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The objectives of this study were to 1) explore the feasibility and benefits of incorporating interactive job-aiding techniques into an interface to electronic documentation for depot-level maintenance tasks, 2) identify candidate job tasks for electronic aiding, 3) develop an initial concept for an interactive maintenance-aiding system (IMAS), and 4) develop a roadmap for implementation of an IMAS, including prototype development.

The relationship of the proposed interface-oriented IMAS to the paper-oriented Automated Technical Order System (ATOS) is discussed. It is recommended that a menu-based authoring system for creating state-of-the-art electronic aiding interfaces, using ATOS and related files as input, be developed. This authoring system would allow depot maintenance managers and supervisors to compose, compile, and update maintenance-aiding materials to be used for interactive presentation to the technician.

Prototype development and implementation plans are presented for two application areas: the Precision Measurement and Equipment Lab (PMEL) and F-16 checkout.

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22a NAME OF RESPONSIBLE INDIVIDUAL
John A. Modrick

22b TELEPHONE *(Include Area Code)*
612-378-5016

22c OFFICE SYMBOL

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SECTION 1

INTRODUCTION

This report documents an analysis of the needs of depot-level maintenance technicians for interactive information aids for job performance. Sophisticated aids will be made possible by the introduction of the Automated Technical Order System (ATOS) for electronic documentation to Air Logistics Centers (ALCs). The analysis was performed under contract to Battelle by Honeywell's Systems and Research Center (Contract No. DAAG29-81-D-0100).

1.1 OBJECTIVES

The objective of the study was to explore the feasibility of incorporating interactive maintenance-aiding techniques into an electronic documentation interface for depot maintenance. The advent of electronic documentation of technical orders (TOs) through ATOS creates both a need and an opportunity. There is a need to provide the technician with an effective interface to the new medium. There is also an opportunity to improve the form of information delivery and thus maintenance efficiency.

The study focused on identifying the information presentation needs of maintenance technicians and determining the interface requirements and supporting system concepts for meeting those needs.

Long-range objectives are to ensure that the use of interface and aiding techniques keeps pace with the use of advanced information storage, manipulation, and delivery technologies. Then the full potential of electronic documentation for productivity and error reduction can be reached.

1.2 SCOPE

This study focused on the requirements for an interactive maintenance-aiding system (IMAS), an information presentation system concept suitable for depot maintenance applications and compatible with ATOS, which is under development. The study also assesses the feasibility of incorporating advanced performance-aiding techniques into depot maintenance activities and identifies the potential benefits of such aiding.

This study was an exploratory effort resulting in a number of recommendations for designing and implementing a system for creating and maintaining electronic documentation interfaces for maintenance technicians. The study did not involve the design or construction of actual systems.

A variety of maintenance activities at the Ogden ALC were reviewed. Information needs for job performance were examined, and current practices were compared to those needs. Job areas that could benefit from application of an IMAS were identified.

An IMAS concept was developed to meet perceived aiding needs. The recommended technician-oriented IMAS will be an adjunct to ATOS, adapting the materials from the electronic TO documentation to job-specific requirements at the depot level.

Prototype applications of interactive aiding systems for several appropriate areas are recommended along with plans for their development.

1.3 PROBLEM OVERVIEW

1.3.1 Limitations of Conventional Technical Orders

Thirty years of research on job performance aiding and design of procedural job guides have consistently shown that less trained and experienced personnel

equipped with well-conceived job aids can perform maintenance tasks at the same level of competence as more highly trained and experienced technicians. Although job performance aids and procedural guides have not been widely adopted as part of the maintenance documentation of weapon systems, research results have had a discernible effect on the form and content of TOs. For instance, the job guides for the F-16 Maintenance Integrated Data Access System (MIDAS) embody the step-by-step performance-aiding concept.

Unfortunately, from the perspective of their use in job applications, the improved TOs suffer most of the same shortcomings as conventional TOs. These shortcomings, listed below, are frequently noted in the literature (Reference 1).

- Multiple cross-referencing is required both within and between volumes.
- Search time to identify, locate, and retrieve relevant portions of manuals is long.
- Information is often obsolete or inappropriate as a result of delays in updating.
- Information is often difficult to understand as presented.
- The medium is inflexible in adapting to the skill level of the technician.
- Volumes are large and bulky.
- Too little or too much information is presented.

MIDAS is a large step forward in reducing the shortcomings of traditional TOs. It has a less bulky format and presents procedures in two levels of detail.

However, the paper format of these volumes precludes a real solution to the problems of cross-referencing, updating, and comprehensibility. An ideal medium for providing technical information and job instructions to a technician should:

- Provide only the information needed for the task at hand
- Provide current and automatically cross-referenced information
- Retrieve all information by entering a task
- Allow graphic and pictorial materials to accompany textual procedures
- Cross-index related items
- Offer more detailed explanations, definitions, technical context, and procedural rationale on request
- Present information on a display that does not require looking away from the task

An electronic interface with integral, interactive aiding can satisfy these requirements by achieving the real-time manipulation and dynamic user-interactive aiding that takes full advantage of the job aiding concept that MIDAS reflects.

1.3.2 Electronic Documentation under ATOS

Currently, traditional paper TOs used in military aircraft maintenance are being converted to electronic documents under the multiphase program, ATOS. The first phase of the program was to develop a computer system and software for preparing, compiling, and printing TOs. The first-phase prototype system has been installed at Ogden ALC. At present, only depot-level TO changes are being entered into the system at Ogden.

The objective of the second phase, currently in progress, is to provide a ground network for distribution of the information in ATOS to maintenance organizations, weapon system managers, and support personnel on a base. The distribution system must include an interface in each organization or functional unit by which the users of TOs can retrieve portions of the technical manuals relevant to specific tasks within a job.

The TOs in the present form of ATOS are conventional paper documents that have been digitized for storage and processing by a computer. The computer's primary

delivery function at this point is to access user-designated sections of a TO. Such systems have been characterized as "electronic page-turners" in the sense that the basic format is equivalent to that of traditional, paper-based information systems. The system is a first step in the general trend toward electronic documentation and the elimination of paper; the system electronically stores documents and efficiently produces hard copy. Substantial savings will be achieved in the preparation, printing, and distribution of manuals. Furthermore, the ease and speed with which changes in a TO can be made and distributed will improve the quality of maintenance and reduce the cost of making the changes.

1.3.3 Relationship of IMAS to ATOS

Electronic documentation is a medium that can be configured to possess properties significantly different from the basic page-turning functions of a paper-oriented system like ATOS. These properties can provide useful interface options in format, information organization, access, and the mix of textual, graphic, and pictorial materials. From the user's standpoint, these options offer greater ease and speed in retrieving integrated information relevant to the user's task. These advantages are achieved with access techniques that reduce the complexity of maintenance instructions by presenting only what is needed or requested. Efficiency can be further increased with presentation techniques that reduce the cognitive, memorial, and perceptual demands on the technician.

A paper-oriented system like ATOS cannot be expected to deliver the kind of electronic documentation described above. The primary purpose of ATOS is to provide an archive for the engineering and logistic information for a weapon system in a format compatible with hard-copy production. Because it is designed for hard-copy production, ATOS is not structured for the production of sophisticated aiding interfaces.

We recommend that the ATOS program not be overloaded with facilities for producing the kinds of technician interfaces described in this report. Instead, a companion system should be developed for this purpose. To produce an optimal interface for maintenance aiding, paper-based information must be reorganized for an integrated presentation and preferably filtered for relevance to the particular checkout, diagnosis, or repair tasks being performed. The ideal maintenance interface must:

- Display only those TO procedures relevant to a given task
- Provide easy or completely transparent cross-referencing between procedures
- Integrate text and graphics
- Aid in the easy identification of parts and components through the use of highlighting and other perceptual aids

In its present form, ATOS is not capable of providing the maintenance interface needed by depot-level technicians. To take advantage of the new medium, the interface should entail more than the simple electronic retrieval of TOs, as in ATOS. The opportunity exists to incorporate a variety of performance-aiding techniques as an integral part of the maintenance instructions received by the technician. This aiding should increase productivity by:

- Reducing the time spent finding relevant sections of TOs
- Increasing the clarity and comprehensibility of the procedural instructions
- Simplifying the maintenance tasks
- Reducing the cognitive demands imposed on the technician

1.3.4 The Need for Depot-Level Work Package Authoring

A depot maintenance organization should have the local capability to prepare depot "work packages" that integrate procedures, information, and pictures into

task instructions for performing specific jobs. These work packages could be based on material retrieved directly from ATOS files. However, to create an adequate interface for the technician, ATOS material will need to be modified, reformatted, and supplemented with state-of-the-art electronic aiding techniques appropriate to the task and technician.

An "authoring system" would allow depot maintenance managers and supervisors to compose, compile, update, and maintain these work packages. The authoring capability should be independent of, but compatible with, ATOS files and software. It must permit information derived from weapon system experience and local maintenance history and practices to be added to the work package. It should also alert users to changes in TOs so that they can infer and implement changes in work packages--changes that cannot be made at the ATOS level.

ATOS should not be expected to provide these work packages or the software for an authoring capability that would provide sophisticated aiding at the interface. Rather, the highest priority objectives for ATOS are to compile, maintain, and distribute an engineering and logistic archive. The technical manuals are a reference source used by several classes of people in addition to maintainers: supply specialists; transportation specialists; operators; design and service engineers; and curriculum planners, trainers and students (Reference 2). The needs of these users require a complex mixture of information in a variety of formats not necessarily relevant to maintenance activities.

1.4 THE TECHNOLOGY OF INTERACTIVE MAINTENANCE AIDING

1.4.1 Maintenance-Aiding System Configurations

Interactive maintenance-aiding systems provide real-time support to maintenance technicians performing checkout, fault isolation, and repair tasks. They can be built using off-the-shelf equipment for interactive graphics, video and audio storage, and voice interaction. These systems can present procedural guidelines

and supporting information to the technician using a display medium, such as a visual display unit (References 3 through 6). Thus instructions can be presented directly and rapidly in a nonintrusive manner.

Such a system eliminates retrieving printed copies of manuals, locating sections relevant to the task being performed, and cross-referencing within and among manuals. Depending on the capabilities provided, the technician can be presented with a list of task steps that contains technical data and highlights significant features and events. A short video segment can be used to demonstrate a procedure that the technician can emulate.

An IMAS can be custom-designed to fit the requirements of a specific application by the selection of different implementation options in display, input, and storage media. Display options include the CRT, electroluminescent panel, liquid crystal, and helmet-mounted display. Input can be made by keyboard, touch screen, and/or voice recognition. Storage mechanisms include hard or floppy disks for digitized alphanumeric text, graphics, and data, and video or optical disks for pictorial material and motion pictures. An interactive aiding system can be adapted to the conditions of each application by selecting appropriate options in each category.

The flexibility provided by these options offers systems that can reduce the time spent in nonproductive and disrupting activities and thus increase maintenance productivity. These advantages are further enhanced when performance-aiding techniques are incorporated. A nominal or baseline system configuration is a conventional CRT display on a desk or benchtop with a standard keyboard or touch screen. The storage medium depends on the quantity and type of information. This configuration is adequate for a large range of applications. However, a small, lightweight, portable microprocessor would be appropriate when the technician must be mobile, as in flight-line maintenance.

Several other variations are appropriate for special work environments or conditions. For instance, retrieval of information by voice commands leaves the

technician's hands free to manipulate equipment while monitoring a display. A laser disk can provide a high-fidelity motion picture of an expert performing a procedure that is not easily or adequately described by words alone. Finally, if the display is helmet-mounted, the information is available even in cramped spaces where there is no room for a TO or display terminal.

1.4.2 Criteria and Techniques for Aiding Maintenance Tasks

There are two places for storing the information needed by the maintenance technician for successful problem solving: in the technician's head or in external sources, such as technical manuals. Neither form is completely adequate for supporting maintenance activities. Human memory is typically not adequate given limited training resources and experience. Information retrieved from memory tends to be incomplete, inaccurate, and unreliable. The number of maintenance procedures, the amount of task-specific data, and the possibly infrequent performance of any single maintenance task force the techician to rely on external sources.

1.4.2.1 Limitations of Paper Aiding--Unfortunately, the best available manuals, represented by the conventional TO system, are also inadequate for supporting the technician's performance. Interactive maintenance aiding is an approach to providing a supplementary form of documentation that can overcome the limitations of the technician's memory and the conventional manual.

Table 1 presents a summary of aiding techniques. Aiding solutions are presented in conjunction with task requirements. In general, task requirements can impose excessive cognitive demands on the technician in the form of short-term and long-term memory, perceptual filtering of visual information, selective attention, interpretation, and inferencing. Table 1 presents both electronic and paper solutions. Electronic solutions utilize recent advances in computer technology, especially in interactive graphics, windowing techniques, and digitized pictorial imagery. Paper solutions are generally a subset of the

TABLE 1. SUMMARY OF TASK CHARACTERISTICS AND RELEVANT TECHNIQUES FOR AIDING JOB PERFORMANCE

Task Requirements	Cognitive Demands on Technicians	Example	Aiding Solutions	
			Paper TO System	Electronic IMAS
Many steps Performed infrequently Specific data	Long-term memory	Avionics system checkout Periodic maintenance Calibration	Job guides Fault isolation manuals	Integrated manuals Hypertext
Integration of information, data, pictorials, and graphics	Short-term memory Inferencing Interpretation	Trouble-shooting	Pictorial locations Keyed schematics Indexing	Pictorial locations Keyed schematics Windowing/split screens Animated block diagrams Video disks
Identification of special features	Perceptual filtering of visual information Selective attention	Visual inspection Part identification	Boldfacing Photographs *Illustrations*	Highlighting, color inverse video, etc. Decluttering Digitized photographs Illustrations
Location of task Limited workspace Two hands required	Psychomotor ability	Remove, replace, and repair	Smaller manual Pocket-sized procedure cards	Portable display units Helmet-mounted display Voice input/output, touch input
Error risk Damage to personnel or equipment	Selective attention to details	Remove, replace, and repair	Checklist Quality checks	Checklist integrated with manuals and required operator input

electronic methods. Electronic aiding is broader in coverage, more interactive, faster in execution, and more convenient to use in real time.

Paper aiding is an approach that has been explored by the armed services. The PIMO program (Presentation of Information for Maintenance and Operation) established the characteristics of the presentation format for current paper aiding techniques (Reference 1). These characteristics include:

- Relevant and complete information presented only
- Procedures broken down to the task level
- Standardized sentence structure and line length
- Improved access to information through indexing

These characteristics have been shown to be effective in reducing total elapsed time and maintenance errors (Reference 7). However, their effectiveness is limited by the presentation medium. Paper manuals are unable to present only the information appropriate to the skill level of the technician for the task at hand. The use of job guides and fault isolation manuals are attempts to overcome this problem, but often they present too little or too much information. This problem, combined with the growing size and number of technical manuals, increases the time required to access relevant information, thus degrading the utility of manuals.

1.4.2.2 Capabilities of Electronic Aiding--An electronic aid can accommodate all of the paper aiding techniques and incorporate new technologies to overcome the limitations of current TOs. Cross-referencing can be performed automatically, for example, and information can be presented at any desired level of detail. The use of paper manuals is made obsolete as the technician can access information by calling up a specific avionics system. "Hypertext" is a means for obtaining definitions, explanations, or more detailed information. Supporting information can be accessed by key word selection, allowing the operator to display additional details only when needed.

A range of possible solutions is usually available for a given performance-aiding problem. Once the need for an information aiding system is demonstrated, the specific design details can be developed through the examination of task requirements listed in Table 1. For example, trouble-shooting tasks place a demand on the short-term memory of the technician, who must simultaneously track different types of information, such as the location of a part, circuit diagrams, block diagrams, and specific data (e.g. voltage readings). The job guide system uses pictorial locators, keyed schematics, and indexing to ease the integration burden, but it forces the technician to remember several pages of information from one or more manuals.

An IMAS can provide all of these capabilities and allow simultaneous viewing of these sources through the use of windowing or split screen techniques. The use of animation further reduces this burden. For example, the technician can view the path of electrical flow in a circuit diagram. Video disks can provide instruction for tasks requiring integrated procedures, such as those that cannot be explained by traditional alphanumeric presentation.

An electronic information aid can also reduce perceptual demands on the technician. Paper information aiding solutions to perceptual demands include boldfacing, photographs, illustrations, and highlighting. These aid the technician in picking out information from the manual, identifying parts on the aircraft, and viewing overall relationships between components or systems. An electronic aid can provide these solutions as well as information filtering, which tailors the information to the specific skill level of the technician. In addition, digitized photographs can be rotated or expanded so that the technician can receive contextual information for part location and component relationships.

If the task requires extensive attention to detail, a paper aid can provide a checklist of procedures for the technician. However, this produces additional pages of documentation. The technician must integrate them and keep place in

the checklist. An electronic checklist can present a limited number of steps at a time and demand that the operator check off each step before the next step is presented. Related information from other sources can be easily integrated automatically. For example, if a specific instruction on a checklist is familiar, the maintenance technician can perform the task and indicate to the system that it is finished. If an instruction is not familiar, the technician could request additional instructions from the system.

Electronic aiding can improve aircraft repair tasks that require the technician to perform activities in restricted, cramped spaces or in areas that are not near the location of the TOs. These situations normally increase the maintenance repair time by requiring the technician to make several trips to the TO outside of the work space or by requiring an additional technician to retrieve TOs and find the necessary information. The latter activity is also necessary when the job requires the technician to use both hands. Advances in hardware for electronic aiding systems, such as portable display units, helmet-mounted displays, touch input, and voice input/output, can alleviate these problems by bringing the information source to the task area and allowing access of relevant data with little or no use of the technician's hands.

1.4.3 An Example of Interactive Electronic Aiding

An example of electronic aiding will be presented here for the job of calibrating a radar using radar test set AN/APM 383. This set is a special purpose, portable tester used to maintain continuous wave illuminator radar equipment. It measures RF power, spectral purity, and coding integrity of signals generated by the radar equipment.

There are five technical manuals written for this equipment: operation instructions (TO 33D7-44-219-1), calibration procedures (TO 33D7-44-219-2), intermediate maintenance instructions (TO 33D7-44-219-12), overhaul instructions (TO 33D7-44-219-4), and illustrated parts breakdown (TO 33D7-44-219-4).

The electronic aiding approach consists of integrating the information from these manuals into one procedure, to be accessed by menu selection. Figure 1 presents a sample menu structure for the overhaul instructions. The integrated information was organized into a menu structure so that the user can obtain information at increasing levels of detail. Each manual becomes an item on the highest level menu for the radar test set. Once the desired level of information is selected, the technician can choose between procedural instructions and supporting information. Both categories are broken down through three levels, terminating at block and circuit diagram descriptions (supporting information) and procedural steps for test set up and test (procedures).

Figures 2 through 6 present sample interfaces based on this menu structure using a CRT with windowing and a touch screen. These figures present a possible sequence of information retrieval for a technician performing the ninth test step of the checkout procedures for voltage regulator assembly A1A22.

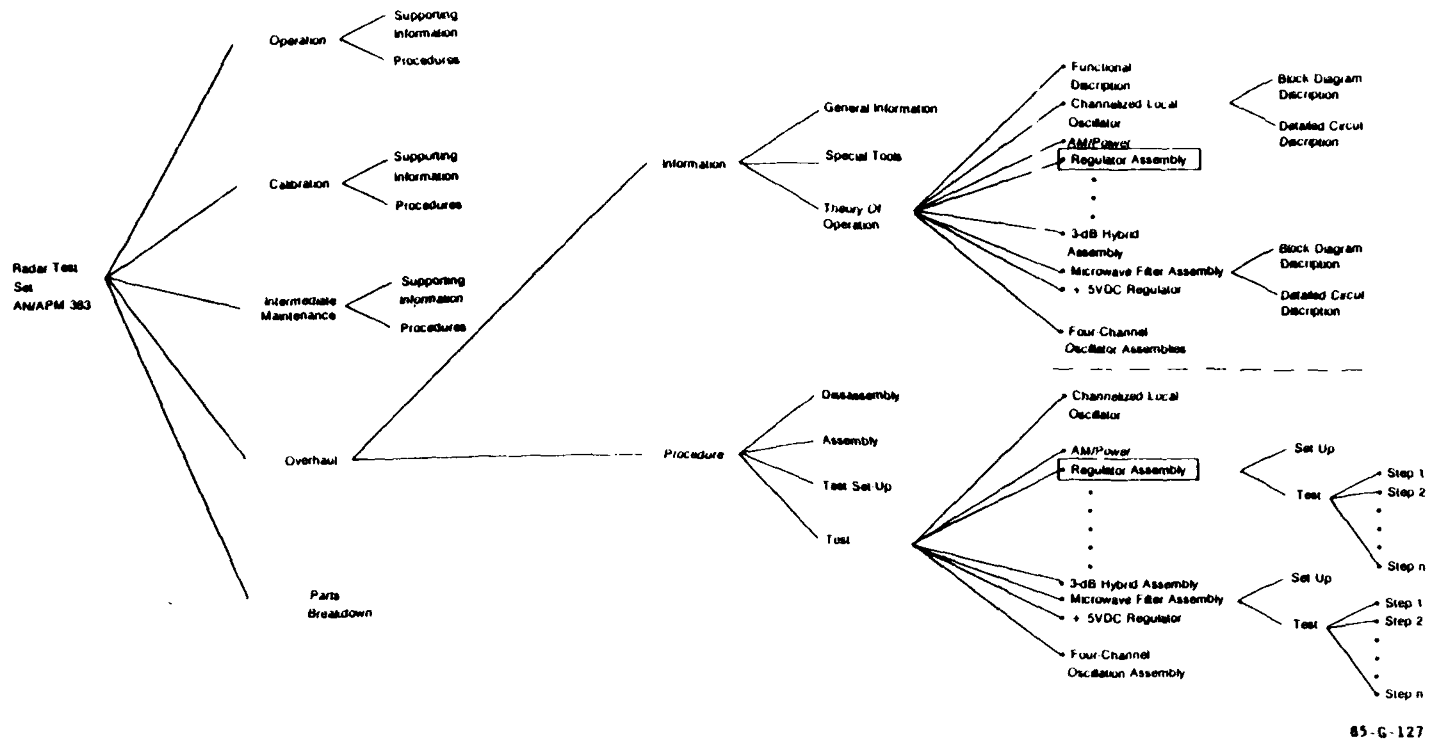


Figure 1. Menu Structure for Calibration Instructions for the Radar Test Set AN/APM 383

The displayed instructions for this test step are presented in Figure 2. Test procedures are presented on the left portion of the screen and results and abnormal-action directions on the right. Key words are used to allow operator access to additional information on this procedure. Touching any of the uppercase words produces a menu of available information categories on the lower portion of the screen. In this example, the technician touches "Q5" to obtain more information on that component.

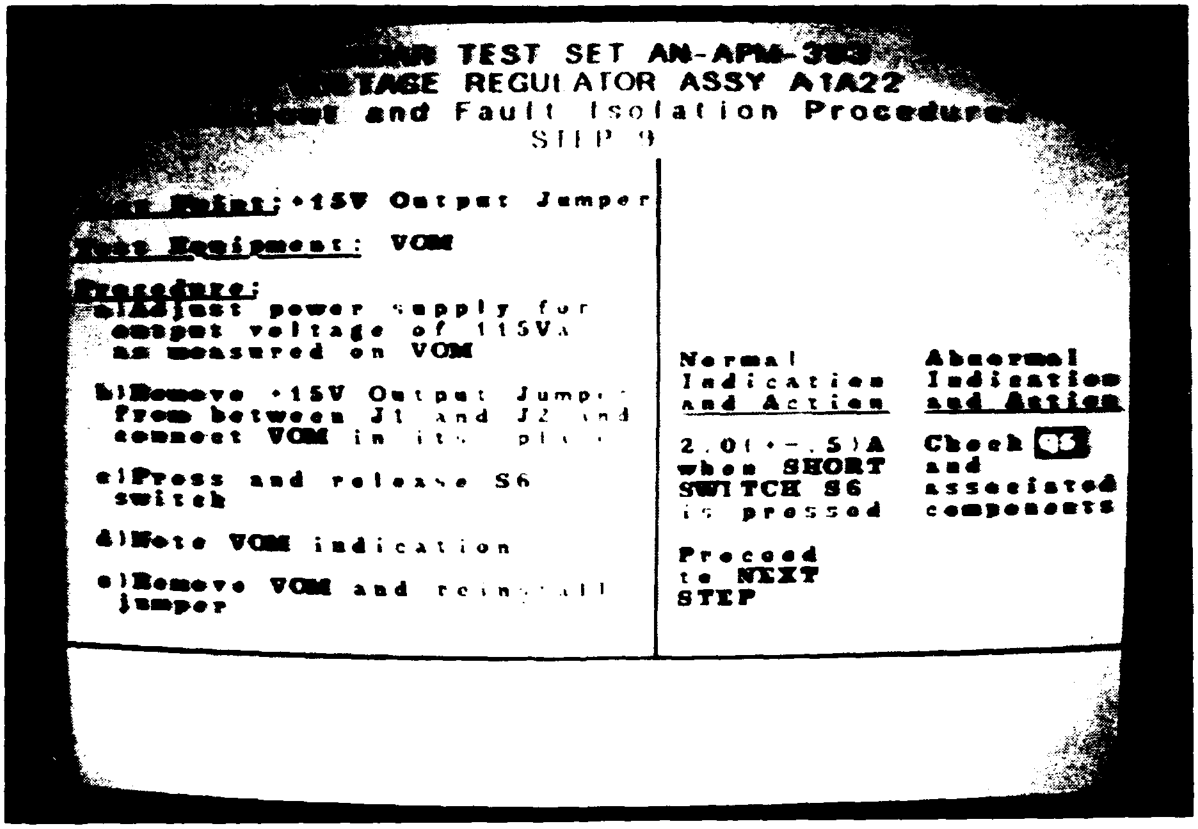


Figure 2. Display for the Ninth Test Step in Checkout of Voltage Regulator Assembly A1A22

The request for more information on Q5 is followed by the display shown in Figure 3. A menu of available information on this component appears at the bottom of the display. When "CIRCUIT DIAGRAM" is selected, the display changes to the circuit diagram presented in Figure 4; the right half of the screen is blank.

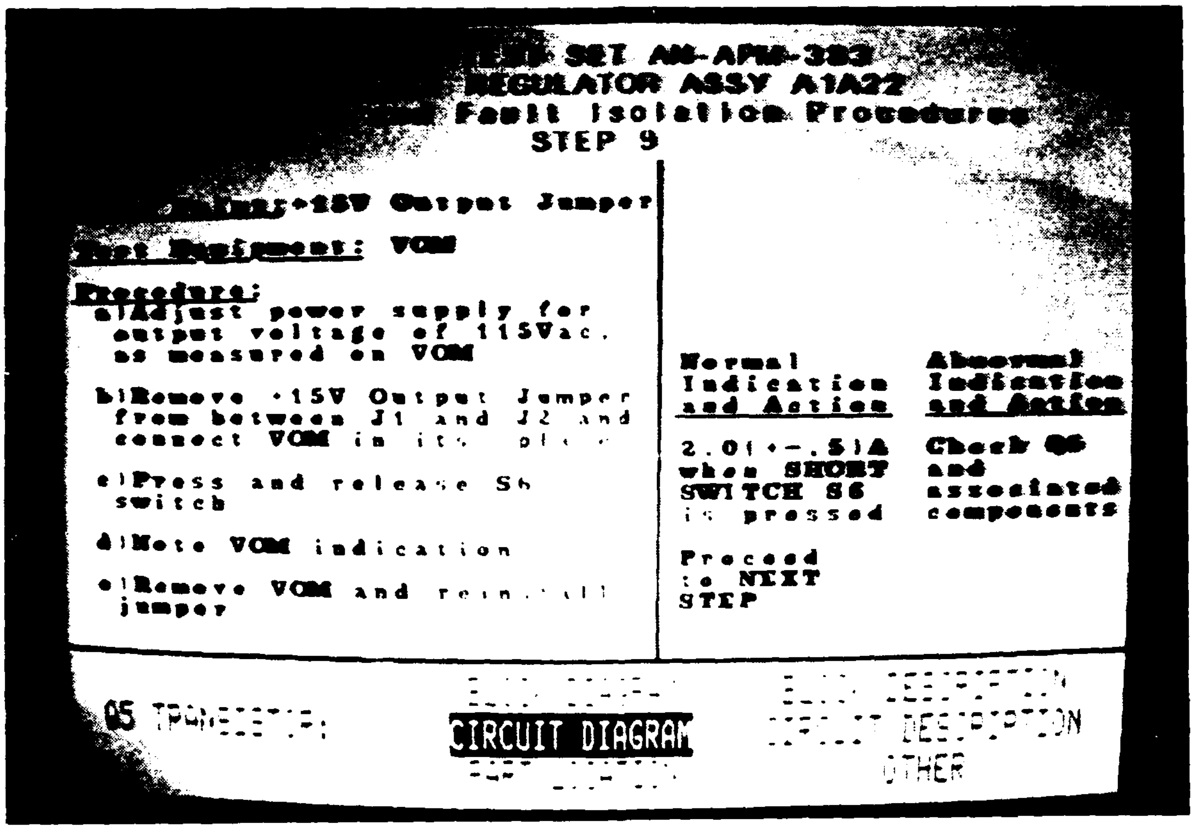


Figure 3. Display of Menu on Bottom of Screen to Call for More Information; Evoked by Touching "Q5" in the Upper Part of the Screen

Touching "Q5" on the circuit diagram results in the display of information on Q5 on the right half of the screen in Figure 4. The menu also appears again at the bottom of the screen. "CIRCUIT DESCRIPTION" is now selected by touching that part of the screen.

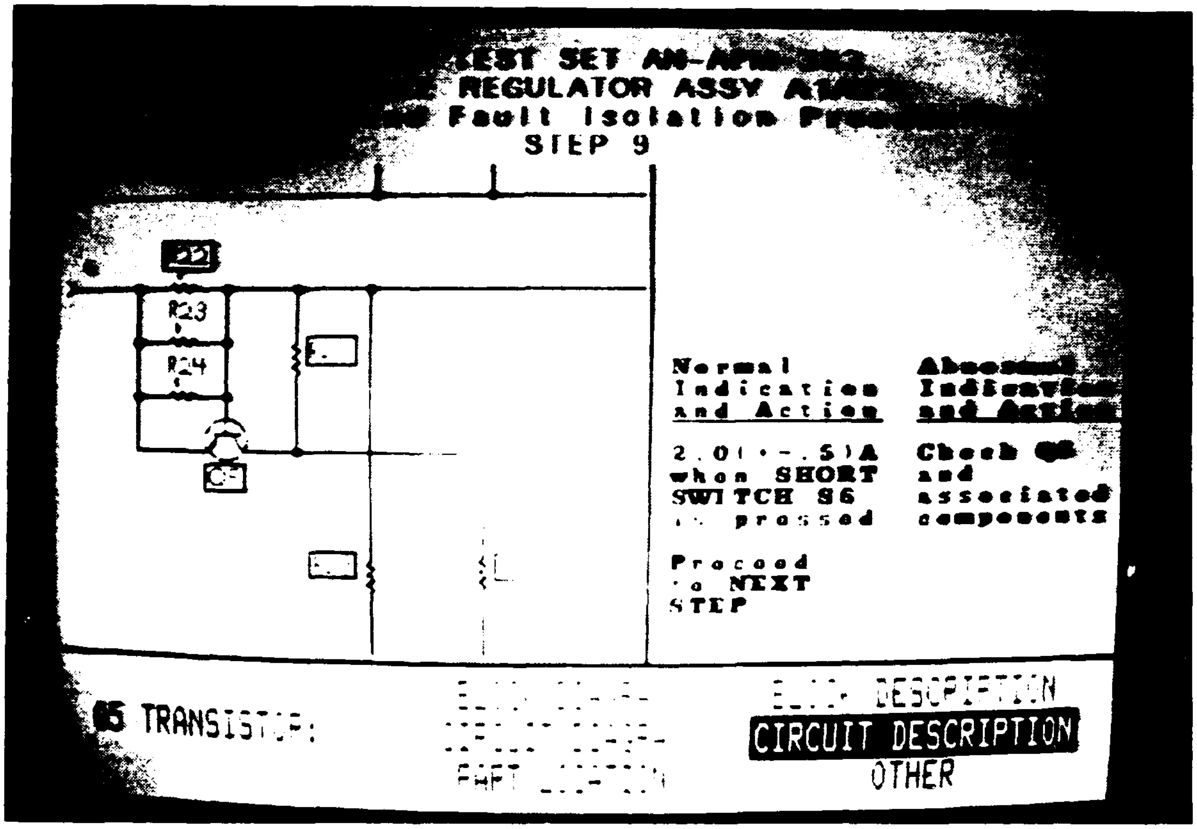


Figure 4. Display of Circuit Diagram Containing Q5; Technician Requests More Information by Touching "CIRCUIT DESCRIPTION" at Bottom of Screen

The display on the left side of the screen in Figure 5 is a diagram of the circuit containing Q5 and associated components. Control commands appear in the lower left; the technician would use them for scrolling the diagram. In this example, the technician desires more information on this component and touches "Q5" on the circuit diagram.

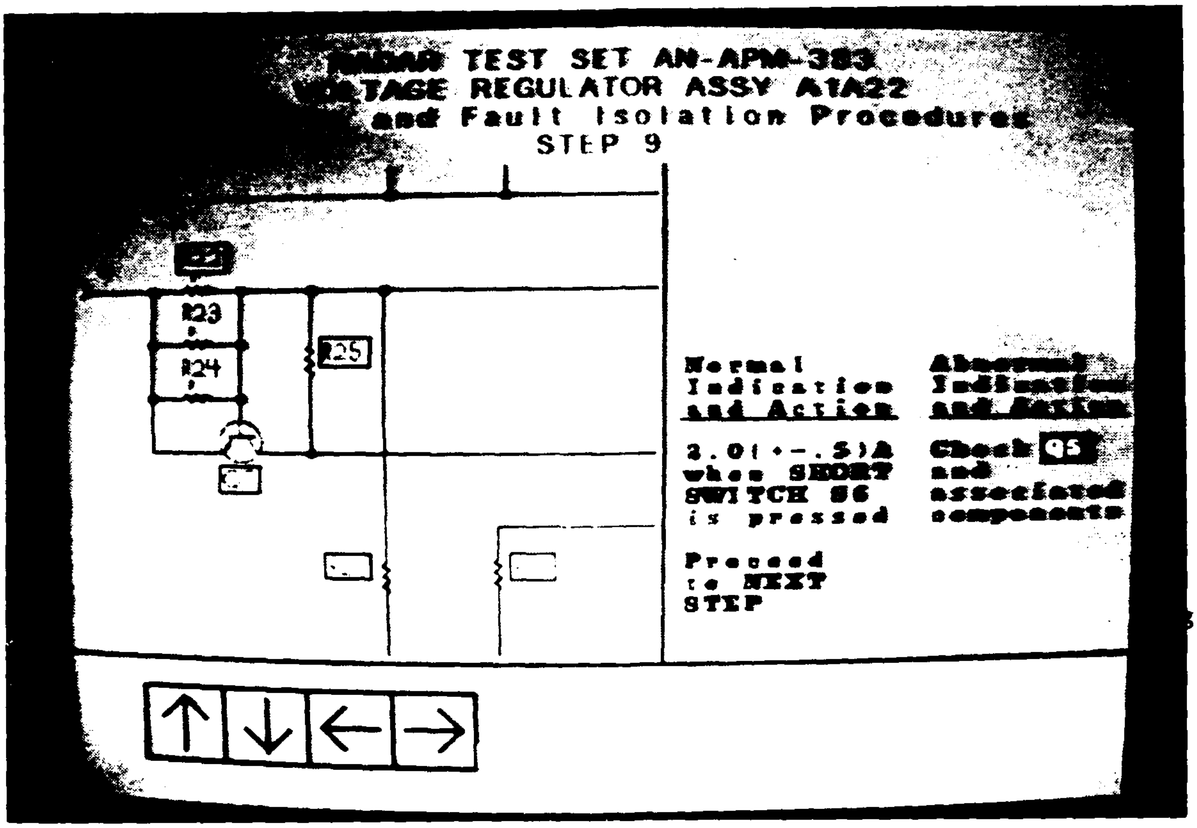


Figure 5. Display of Circuit Diagram Containing Q5 with Symbols for Scrolling Commands; Touching "Q5" Again Calls for More Information

The circuit diagram appears on the left half of the screen in Figure 6. Commands for viewing additional information or recalling previous information are also available.

This system would provide easy access to all information available on the radar test set.

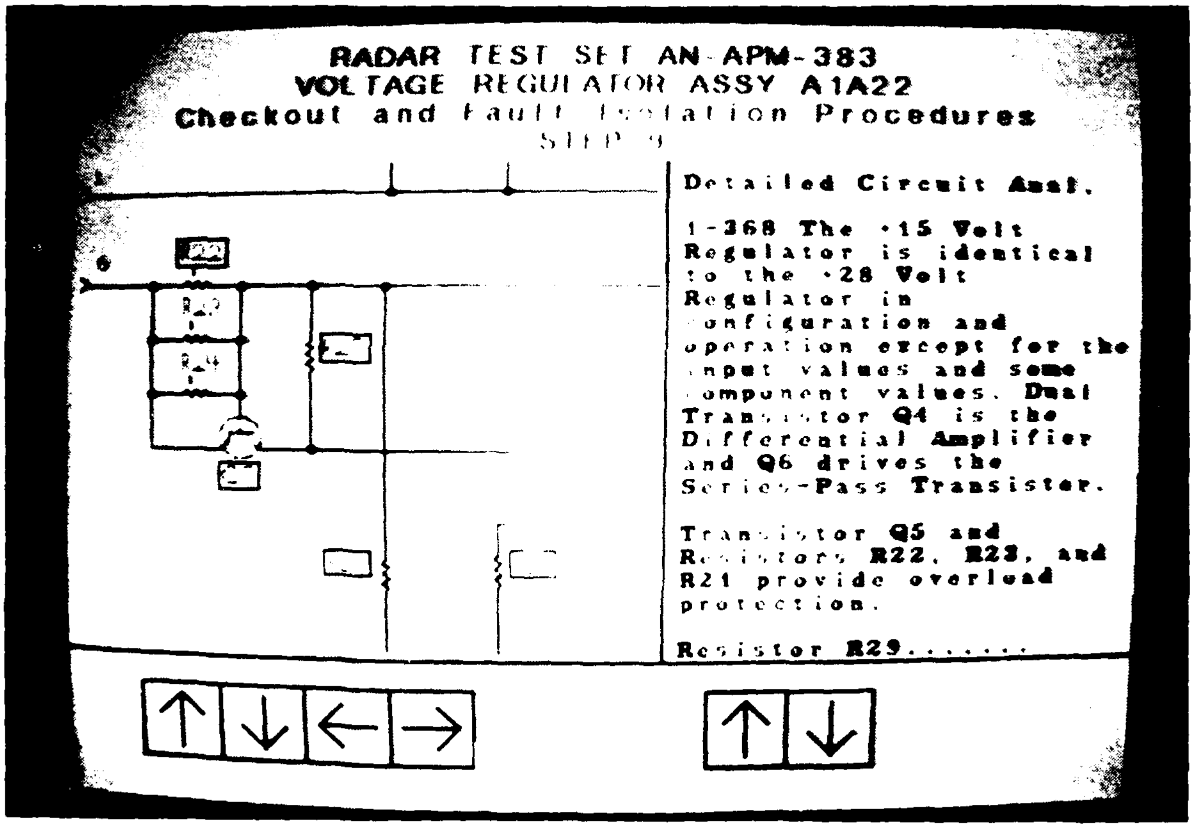


Figure 6. Presentation of Requested Circuit Information and Symbols for Scrolling Commands

SECTION 2

REVIEW OF OGDEN ALC MAINTENANCE ACTIVITIES

The basic objectives of this study were to assess the feasibility of implementing an interactive maintenance-aiding system (IMAS) for depot maintenance tasks and to develop a roadmap for developing and installing such an ATOS-compatible system at Ogden ALC. If feasible applications were found, then the development required to design and build a limited prototype for test and evaluation was to be identified. This developmental work was to be described at a level necessary to set up a program plan and provide a basis for preparing requests for proposals to develop the prototype(s).

2.1 APPROACH

The approach consisted of five steps.

1. Collect information on maintenance tasks at Ogden ALC.

2. Identify candidates for IMAS application in job areas that offer potential benefits.

3. Recommend a limited set of applications for system development.

4. Select and describe IMAS prototypes for development.

5. Outline a developmental roadmap for installing an IMAS at Ogden ALC.

Valuable sources of information were interviews and observations of maintenance activities made during three visits to Hill Air Force Base (AFB). Discussions

were held with planners, supervisors, and experienced technicians in several shops, facilities, and laboratories. Relevant descriptive literature and TOs were obtained and reviewed.

Candidate job areas were surveyed to identify those that are most dependent on TOs for successful performance and therefore offer significant potential benefit for aiding. The criteria listed in Table 1 were used to determine those maintenance areas with the highest need for information aiding. Although TOs are required for all maintenance activities, some tasks are more dependent on them than others. In this investigation, the most critical task requirements were those demanding long-term memory and visual perception. A first cut was made at determining information requirements, desirable aiding techniques, and an aiding system concept. Candidate areas selected for further development were then examined in greater detail to obtain additional information on the use of relevant TOs.

In addition, information was gathered on related programs: ATOS; the Integrated Maintenance Information System (IMIS), a developmental program at the Air Force Human Resources Laboratory (AFHRL) at Wright-Patterson AFB; and the Flight Control Maintenance Diagnostic System (FCMDS), a Wright-Patterson Flight Dynamics Lab program for the development of an expert diagnostic system for fault isolation for aircraft maintenance. Information from subsequent visits with key people in these programs and from descriptive documents were used to further formulate an integrated IMAS concept.

2.2 SURVEY OF DEPOT WORK AREAS

Five maintenance areas were visited.

- Aircraft Repair and Modification Facility--Overhaul, repair, and modification of F-4, F-15, and F-16 aircraft are done in this facility.

- Precision Measurement Equipment Laboratory (PMEL)--This organization consists of seven sections that inspect, calibrate, and overhaul all measurement equipment used at Hill AFB. The observations and analyses in this study of PMEL were focused on the Electro Mech/Optical Dimensional Section.

- Landing Gear Division--This organization is an industrial facility for overhaul, repair, and reconditioning of all components of the landing gear (such as wheels, brakes, and associated hydraulics of the aircraft) in the Air Force inventory.

- Sheet Metal Shop--Structural metal repair and modification are done in this shop. A modification to all F-16 wing assemblies was being performed at the time of our visit.

- Automatic Test Equipment (ATE) Facility--Fault localization by the operator after the equipment has narrowed the location of the fault to a limited number of components is an area of potential IMAS application.

Conversations were held with technicians, managers, and planners at each facility to determine what work is done, how it is done, and where TOs and other information sources are needed and used. The objective of this information gathering was to provide information in the following categories:

- The flow of information in the facility
- Maintenance tasks suitable for the initial prototyping of IMAS
- Limitations of the TOs for each task
- How the TOs are used by technicians, planners, and managers
- Other sources of information required for successful task performance
- Recommendations for IMAS design

Maintenance activities were also observed at each facility. In the F-16 modification area, we took a guided "walk through" of the facility from planning to execution of modifications on the hangar floor and into system checkout for flight test. Installation of an electrical generator and the associated power distribution wiring was taking place at this time.

In addition, TOs were obtained for the job areas that were candidates for prototyping. These were examined for task descriptions, type of procedures, use of supporting information, cross-referencing of tasks, potential for performance aiding, level of detail, expertise required for use, and illustrations.

2.3 SUMMARY OF OBSERVATIONS FROM THE REVIEW OF MAINTENANCE ACTIVITIES

The following is a brief summary of our conclusions on candidate task areas.

- Flight test checkout following F-16 modifications can benefit from a time savings of up to 30% by integrating multisource technical information into work packages for presentation. Additional savings can be obtained with electronic presentation techniques.

- PMEL can benefit from multisource integration and memory aiding for lengthy and infrequently performed tasks. Perceptual aiding will also benefit tasks involving unfamiliar or infrequently maintained equipment.

- The tasks at the Landing Gear Division and Sheet Metal Shop will not benefit enough from aiding to merit further investigation. The tasks are highly structured and frequently performed so that they are memorized and mastered even when lengthy and complex. Real-time interactive use of TOs is not routinely required. Interactive aiding is a low priority and would have little benefit.

2.4 DISCUSSION OF WORK AREA ACTIVITIES

2.4.1 Aircraft Repair and Modification Facility

Overhaul, repair, and modification of F-4, F-15, and F-16 aircraft are done in the Aircraft Repair and Modification Facility. Periodic overhaul is a major activity in the F-4 and F-15 areas. These aircraft are mature weapon systems and are in the midphase of their life cycle. While IMAS would be benefical, the extent of benefit and the projected longevity of the F-4 and F-15 reduce the priority of these weapon systems as vehicles for prototype development and evaluation.

The F-16, in contrast, is a relatively new system. Its design configuration and maintenance practices are still rapidly evolving. The main activity of the F-16 facility is performing the aircraft modifications dictated by a continuing series of engineering changes. Each F-16 in the Air Force inventory is scheduled to be updated with all engineering changes that have been made since the aircraft was produced. No repair or overhaul is done except for rebuilding aircraft damaged in accidents or making repairs that cannot be made at the organizational level.

2.4.1.1 F-16 Maintenance Problems--The F-16 maintenance tasks are fraught with information delivery problems because of both the complexity of modern avionics systems and the large number of modifications made to the F-16. Because it is unlikely that any two F-16 planes will have the same configuration, maintenance procedures are different for each airplane and there is a large number of possible procedural combinations. The necessary cross-correlation among modifications, aircraft models, and procedures is time-consuming, complex, and causes a significant cognitive demand on the technician.

There are four different production models of the aircraft. The later models come off the production line with all the modifications of earlier models. Over

800 modifications had been made at the time of our review. For a given plane, some subset of these modifications may have been done in previous visits to the repair facility. When a plane arrives at the facility, a maintenance history record of that aircraft must be consulted to determine its modification status.

Further discussion of the cross-correlation problem requires an understanding of Time Compliance Technical Orders (TCTOs). A modification is made to an aircraft in response to a TCTO. This TCTO contains step-by-step instructions for removing panels and components to get to the site of the modification, performing the modification, and then reassembling the aircraft. Each modification has a procedure designed specifically for that job. Often the work is done using blueprints rather than the TO manuals. However, if a required procedure is in the job guide, the TCTO will refer to the TO rather than repeat the procedure. Once the procedure has been set up, the modification will be made to all F-16s coming into the facility until the entire fleet has been serviced. The procedure changes, however, as experience is gained in making a particular modification.

Table 2 is a page from an index used to cross-reference accomplished TCTOs and aircraft serial numbers to maintenance procedures. The TCTOs are indicated by number; another table contains a description of the modification performed under each TCTO. The numbers under each TCTO are the serial numbers (tail numbers) of the aircraft on which the modification has been made. The white "A" or "B" on black background indicates the model of the craft. The white numbers on black are a cross-reference code to the maintenance procedures. The procedures associated with each modification are interlaced in the manual.

The technician comes to critical points in each procedure at which one of two variants in the procedure applies to the aircraft model being modified. Each variant will be marked with a white number on black background. The technician then refers to the list in the front of the manual to determine if the aircraft has been modified. The manual from which Table 2 was taken has eight pages of this coding dealing with 13 TCTOs for the flight control system.

TABLE 2. CROSS-REFERENCING OF TCTOs AND AIRCRAFT

T.O. 1F-16A-2-27FI-00-1

USAF S/N 79-0332 – 80-0540
EPAF S/N 78-0141 – 80-3546
78-0189 – 78-0203
78-0238 – 78-0257
78-0285 – 78-0299

USAF S/N 79-0420 – 80-0634
EPAF S/N 78-0172 – 78-0173
78-0209 – 78-0211
78-0267 – 78-0271
78-0305 – 78-0307
AND
After TCTO 1F-16-780
USAF S/N 78-0001 – 79-0331
EPAF S/N 78-0116 – 78-0140
78-0174 – 78-0188
78-0212 – 78-0237
78-0272 – 78-0284

USAF S/N 78-0077 – 79-0419
EPAF S/N 78-0162 – 78-0171
78-0204 – 78-0208
78-0259 – 78-0266
78-0301 – 78-0304

Prior to TCTO 1F-16-591 and 1F-16-645
USAF S/N 78-0001 – 78-0021
EPAF S/N 78-0116 – 78-0132
78-0174 – 78-0176
78-0212 – 78-0223
78-0272 – 78-0274

USAF S/N 78-0077 – 78-0098
EPAF S/N 78-0162 – 78-0167
78-0204 – 78-0205
78-0259 – 78-0264
78-0301 – 78-0302

USAF S/N 78-0022 – 80-0540
EPAF S/N 78-0133 – 80-3546
78-0177 – 78-0203
78-0224 – 78-0257
78-0275 – 78-0299

USAF S/N 78-0099 – 80-0634
EPAF S/N 78-0168 – 78-0173
78-0206 – 78-0211
78-0265 – 78-0271
78-0303 – 78-0307
AND
After TCTO 1F-16-591
USAF S/N 78-0001 – 78-0021
EPAF S/N 78-0116 – 78-0132
78-0174 – 78-0176
78-0212 – 78-0223
78-0272 – 78-0274

USAF S/N 78-0077 – 78-0098
EPAF S/N 78-0162 – 78-0167
78-0204 – 78-0205
78-0259 – 78-0264
78-0301 – 78-0302

USAF S/N 78-0022 – 79-0331
EPAF S/N 78-0133 – 78-0140
78-0177 – 78-0188
78-0224 – 78-0237
78-0275 – 78-0284

USAF S/N 78-0099 – 79-0419
EPAF S/N 78-0168 – 78-0171
78-0206 – 78-0208
78-0265 – 78-0266
78-0303 – 78-0304
AND
After TCTO 1F-16-591
USAF S/N 78-0001 – 78-0021
EPAF S/N 78-0116 – 78-0132
78-0174 – 78-0176
78-0212 – 78-0223
78-0272 – 78-0274

USAF S/N 78-0077 – 78-0098
EPAF S/N 78-0162 – 78-0167
78-0204 – 78-0205
78-0259 – 78-0264
78-0301 – 78-0302

USAF S/N 78-0022 –
EPAF S/N 78-0133 –
78-0177 –
78-0224 –
78-0265 –

USAF S/N 78-0099 –
EPAF S/N 78-0168 –
78-0206 –
78-0265 –
78-0303 –
AND
After TCTO 1F-16-591 and 1F-16-645
USAF S/N 78-0001 – 78-0021
EPAF S/N 78-0116 – 78-0132
78-0174 – 78-0176
78-0212 – 78-0223
78-0272 – 78-0274

USAF S/N 78-0077 – 78-0098
EPAF S/N 78-0162 – 78-0167
78-0204 – 78-0205
78-0259 – 78-0264
78-0301 – 78-0302

A/B xiv

We were told by a maintenance supervisor that up to 50% of the technician's time during checkout and trouble-shooting following modifications is spent in paper-based information search. Other sources report that 30% of total job time is consumed by this activity (References 8 and 9). Therefore, improving the methods of obtaining and delivering information is critical for efficiency. Cross-indexing information between procedures and across and within subsystems is a crucial part of the IMAS concept.

The maintenance tasks on the F-16 are also made more difficult by the fact that the F-16 subsystems are more interdependent than prior aircraft. The use of sophisticated electronics to achieve the high performance capability of the weapon system requires a great deal of crosstalk and integration among subsystems that traditionally have functioned with a high degree of independence. The consequence for maintenance is that symptom interpretation is more complex. Negative indicators during checkout and fault localization can no longer be interpreted in terms of a single subsystem. The interactions between subsystems, such as weapons and flight control, must also be considered.

2.4.1.2 The F-16 Modification Process--The process involved in aircraft modification can be divided into three phases: planning, production, and flight test. P ning consists of generating a work plan, a sequence of activities, and a sc le. Production consists of the activities of performing the modification. Flight test is an operational checkout of the aircraft after the modification has been accomplished to verify that the aircraft has been restored to full operational capability. This sequence is described in the following subsections.

2.4.1.2.1 Planning--When the planning department is informed that an aircraft is scheduled for modification, it enters that aircraft into the maintenance schedule. The planners determine which modifications are required by consulting the Aircraft Maintenance System (ACMS). This system contains a list of all F-16 tail numbers and the modifications that have been installed for each.

All documents related to these modifications are collated. They typically fill two drawers of a standard file cabinet. This collation is currently done manually.

The required modifications are entered into the on-site CYBER system, which creates a set of job cards for the aircraft. These cards list the modifications that need to be installed, reference the appropriate TO information, and sequence the modification procedures.

2.4.1.2.2 Production--The job cards with supporting information are sent to the production maintenance foreman, who typically supervises the work on three aircraft. Each card provides the schedule and sequence for the jobs as well as references to the job guides containing relevant procedures. The cards contain the grade of technician required for each job, and the foreman assigns personnel to the aircraft on this basis.

When the modifications are completed, the plane is reassembled. The technicians check out all systems in the aircraft, trouble-shoot, and make any necessary repairs.

2.4.1.2.3 Flight Test--The aircraft is then sent to the flight test facility where the systems are rechecked and the plane is flight tested. If malfunctions surface, the fault is isolated and the necessary repairs or adjustments are made. If the plane passes the preflight inspection and flight test, it is returned to its unit. Otherwise, it is returned to the operations checkout facility.

2.4.1.3 MIDAS--The primary source of procedural information for F-16 maintenance is the Maintenance Integrated Data Access System (MIDAS). It consists of 256 volumes covering 37 subsystems. Six different types of volumes will be described. They are a representative set to which a technician might refer in checking out, trouble-shooting, and repairing an aircraft. This set

includes the Job Guide Manual, Fault Isolation Manual, Wiring Diagram Manual, Illustrated Parts Breakdown, General Vehicle Description, and General System Manual.

2.4.1.3.1 Job Guide Manual--The Job Guide Manual provides step-by-step instructions for all commonly performed tasks except trouble-shooting. There are several guide books for each aircraft subsystem. They contain preliminary information, procedural instructions, and illustrations on fold-out pages. Instructions are presented at two levels of detail. Major steps or subtask headings (e.g., "Remove the gear box") are presented in boldface followed by detailed instructions in standard typeface. The experienced technician who remembers the detailed procedure may use only the boldfaced steps. If the procedure is checkout, references to the trouble-shooting manuals are provided for each test that fails.

2.4.1.3.2 Fault Isolation Manual--The Fault Isolation Manual contains trouble-shooting information in logic tree format. The technician first performs a system checkout using the job guide. When a malfunction is identified, the job guide provides a code number that refers the technician to a page and paragraph in the Fault Isolation Manual. The logic tree provides step-by-step instructions for isolating a fault. The outcome at each step determines the next step to be taken, and the procedure is followed until the fault is identified.

If the fault is identified, a reference is given to the job guide that provides instructions for replacing the faulty component. However, if the fault is not identified, the technician will be instructed to refer to the wiring diagram for further trouble-shooting. At this point, technicians must devise their own trouble-shooting procedures.

2.4.1.3.3 Wiring Diagram Manual--The Wiring Diagram Manual provides diagrams of all aircraft wiring and drawings showing the locations of connectors, ground points, terminal boards, and splice areas.

2.4.1.3.4 Illustrated Parts Breakdown--The Illustrated Parts Breakdown contains illustrations of all aircraft components. It also provides the location in the aircraft, the part number, and a brief description for each component. A second volume provides a numbered list of parts used as an index to the illustrations.

2.4.1.3.5 General Vehicle Description--The General Vehicle Description provides a general description of the aircraft.

2.4.1.3.6 General System Manual--The General System Manual provides a general description of the major avionics systems (e.g., flight control, weapon, etc.).

2.4.1.4 MIDAS Limitations--The format and structure of MIDAS is a dramatic improvement over traditional TO presentation. The MIDAS job guides, for example, are only 8 in. long and 5 in. wide, small enough for use in more confined areas. Yet two major difficulties with MIDAS are still present. First, there are too many manuals and the technician must cross-reference information from several manuals. Second, within a manual, obtaining information on a specific aircraft is difficult, requiring the technician to identify the sections of applicable information and filter or mentally "strip out" information that is not applicable.

Technicians in the operations checkout area rely heavily on these manuals, and it has been estimated that up to 50% of repair time is spent accessing and locating information. Often, two technicians are required to do a job that could be accomplished by one; the second individual serves as an information retriever and disseminator only.

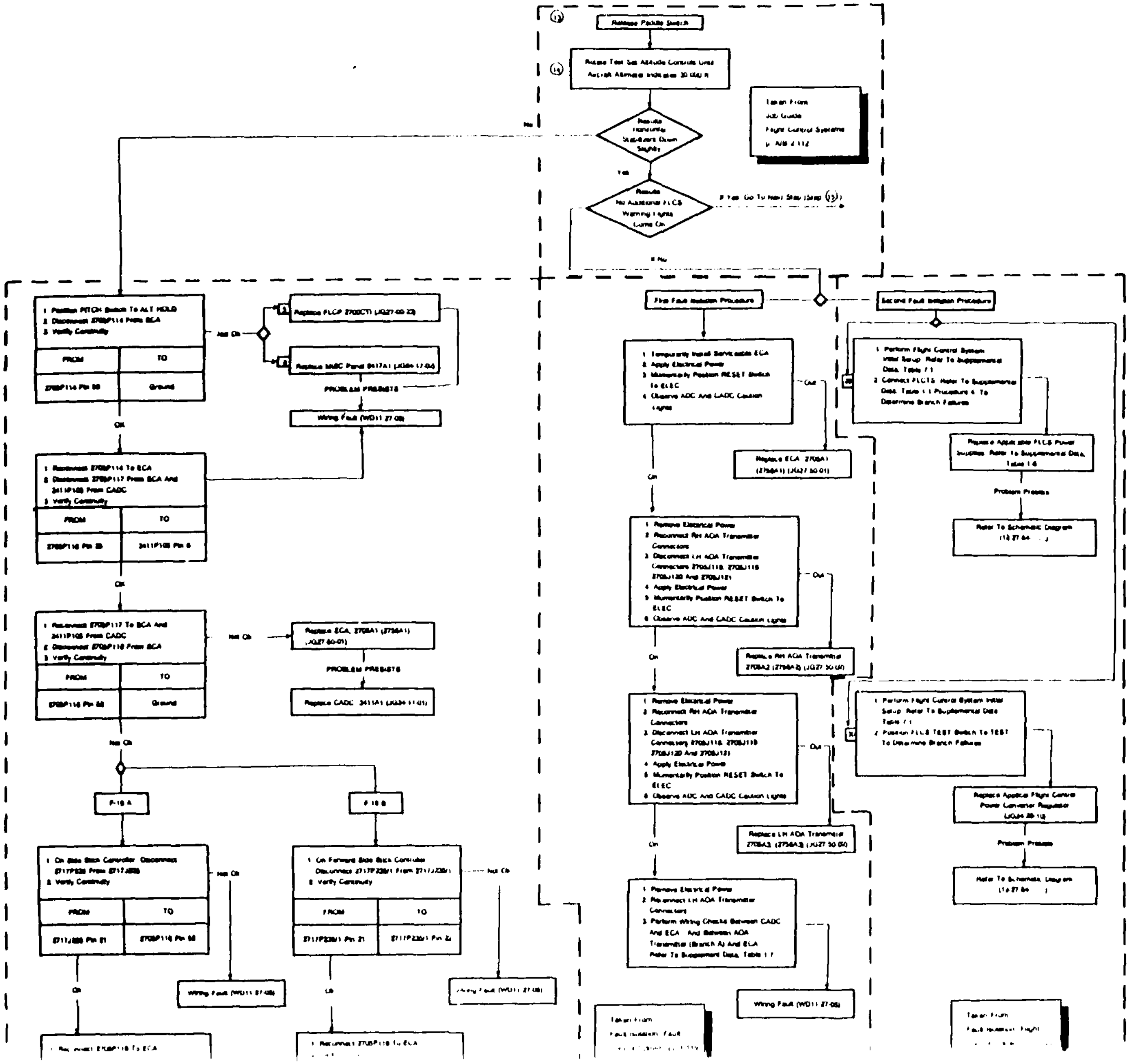
Once the relevant TO section is accessed, the technician must sort the many modifications made to the F-16. These modifications are cross-referenced to procedures and information by aircraft tail number. This information search turns out to be an extremely time-consuming and laborious task.

Figure 7 illustrates the process necessary to use the manuals for checkout and trouble-shooting. This flowchart represents a segment of the procedures for checkout and trouble-shooting of the F-16 autopilot, found in the Flight Control System Job Guide Manual (TO 1F-16A-2-27JG-00-1) and Fault Isolation Manual (TO 1F-16A-2-27FI-00-1).

The upper dotted box in Figure 7 presents a series of checkout steps and expected outcomes found in the job guide. The procedure begins with the actions "Release paddle switch," then "Rotate test set altitude controls until aircraft altimeter indicates 30,000 ft." If the first result ("Horizontal stabilizers down slightly") is not obtained, the technician is referred to a paragraph in the fault isolation manual. The technician must then obtain that manual and follow the procedure there until the fault is isolated. Job guides then must be used to actually repair the fault.

The left dotted box presents fault isolation procedures and recommended actions based on their outcomes. The variation in procedures based on modifications to the aircraft can be demonstrated here. If continuity is not obtained after the first set of instructions, two actions are presented. The index number (5 or 8) refers to a series of tail numbers found in the beginning of the manual, as shown in Table 2. The technician must refer to this list to determine which procedure is appropriate to the aircraft currently being worked on.

In flight test, there is a great need to provide discrete, individually callable procedures specific to the aircraft on which the technician is working. Such procedures would be the result of integration within and between these manuals combined with cross-referencing to the lists of modifications. Material not relevant to a given aircraft would be stripped out to produce a set of procedures specific to each individual tail number. A diagram of a stripped-out procedure is presented in Figure 8.


Release Paddle Switch
First Fault Isolation Procedure
Second Fault Isolation Procedure
PROBLEM PERSISTS
Wiring Fault (WD11 27-08)
F-18 A
F-18 B
FROM
TO
Ground

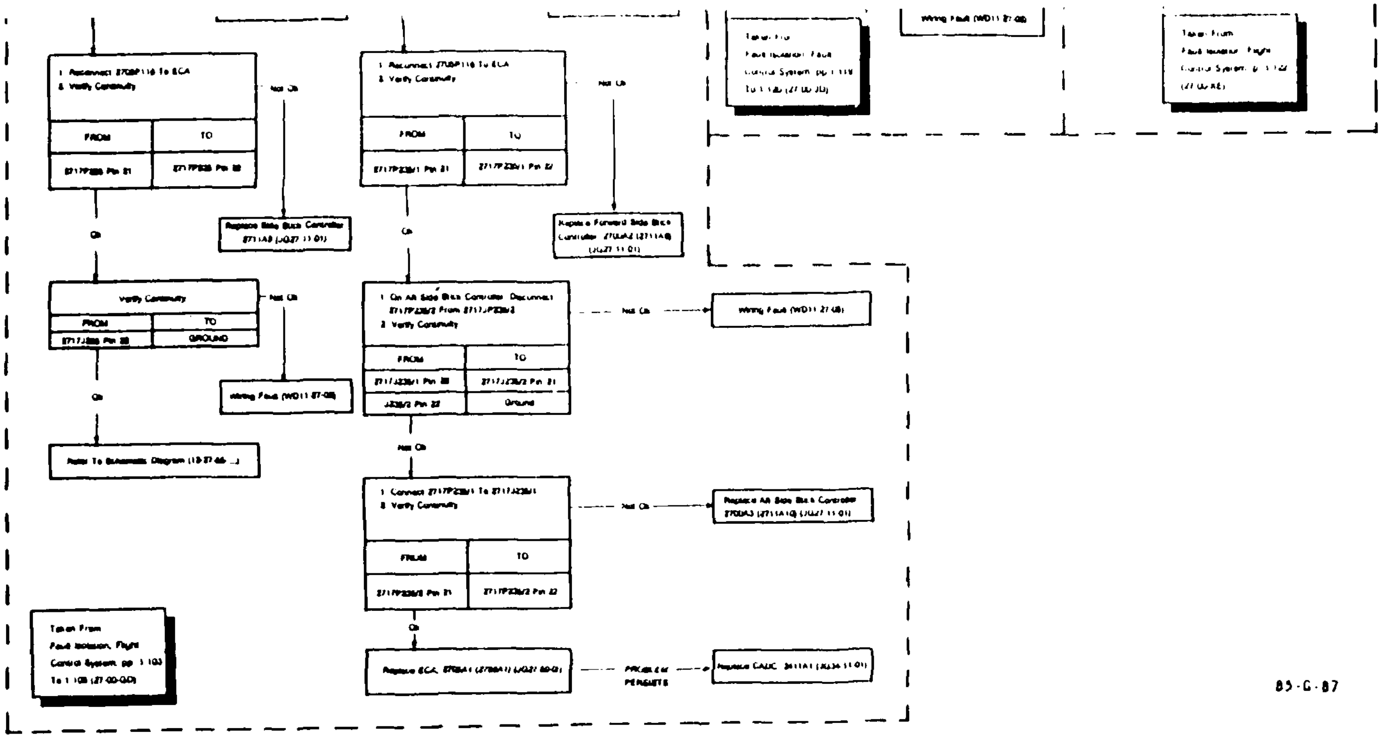
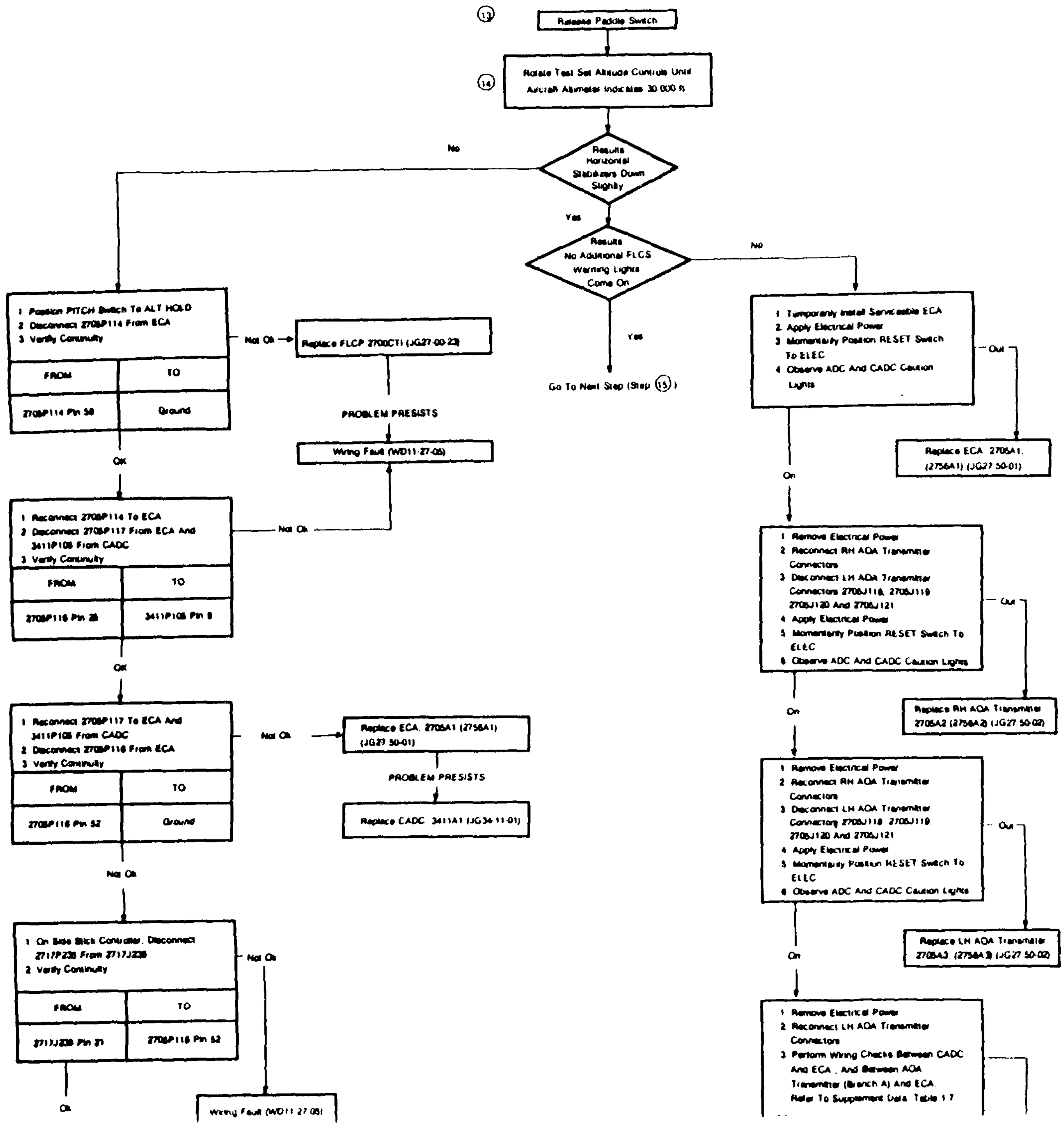


Figure 7. Flow Chart of Procedure for Checkout and Trouble-Shooting of the F-16 Autopilot

PAGE
34 - BLANK



13
Release Paddle Switch
14
Rotate Test Set Altitude Controls Until Aircraft Altimeter Indicates 30 000 ft
Results Horizontal Stabilizers Down Slightly
No
Yes
Results No Additional FLCS Warning Lights Come On
Yes
Go To Next Step (Step 15)
No
1 Position PITCH Switch To ALT HOLD
2 Disconnect 2708P114 From ECA
3 Verify Continuity
FROM
TO
2708P114 Pin 58
Ground
Not Ok
Replace FLCP 2700CT1 (JG27-00-23)
PROBLEM PRESISTS
Wiring Fault (WD11-27-05)
OK
1 Reconnect 2708P114 To ECA
2 Disconnect 2708P117 From ECA And 3411P108 From CADC
3 Verify Continuity
FROM
TO
2708P116 Pin 28
3411P108 Pin 8
Not Ok
OK
1 Reconnect 2708P117 To ECA And 3411P108 From CADC
2 Disconnect 2708P116 From ECA
3 Verify Continuity
FROM
TO
2708P116 Pin 52
Ground
Not Ok
Replace ECA 2706A1 (2756A1) (JG27 50-01)
PROBLEM PRESISTS
Replace CADC 3411A1 (JG34-11-01)
Not Ok
1 On Side Stick Controller, Disconnect 2717P238 From 2717J238
2 Verify Continuity
FROM
TO
2717J238 Pin 31
2708P116 Pin 52
Not Ok
Ok
Wiring Fault (WD11 27 08)
1 Temporarily Install Serviceable ECA
2 Apply Electrical Power
3 Momentarily Position RESET Switch To ELEC
4 Observe ADC And CADC Caution Lights
Out
Replace ECA 2706A1 (2756A1) (JG27 50-01)
On
1 Remove Electrical Power
2 Reconnect RH AOA Transmitter Connectors
3 Disconnect LH AOA Transmitter Connectors 2706J118, 2706J119 2706J120 And 2706J121
4 Apply Electrical Power
5 Momentarily Position RESET Switch To ELEC
6 Observe ADC And CADC Caution Lights
Out
Replace RH AOA Transmitter 2706A2 (2756A2) (JG27 50-02)
On
1 Remove Electrical Power
2 Reconnect RH AOA Transmitter Connectors
3 Disconnect LH AOA Transmitter Connectors 2706J118 2706J119 2706J120 And 2706J121
4 Apply Electrical Power
5 Momentarily Position RESET Switch To ELEC
6 Observe ADC And CADC Caution Lights
Out
Replace LH AOA Transmitter 2706A3 (2756A3) (JG27 50-02)
On
1 Remove Electrical Power
2 Reconnect LH AOA Transmitter Connectors
3 Perform Wiring Checks Between CADC And ECA, And Between AOA Transmitter (Branch A) And ECA. Refer To Supplement Data Table 1 7

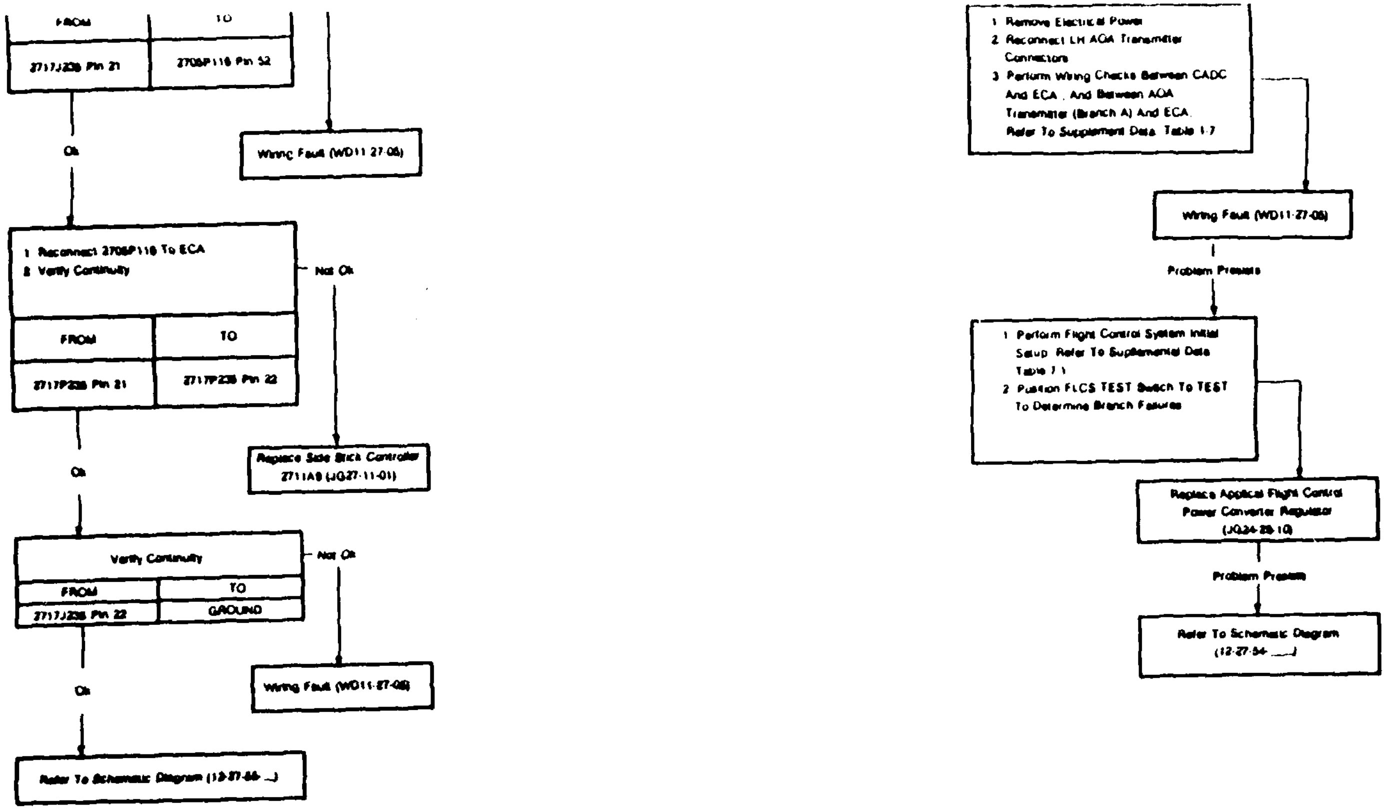


Figure 8. The Stripped-Out Procedure for Checking the F-16 Autopilot

2.4.1.5 F-16 IMAS Candidacy--It is recommended that an authoring capability be provided to compile aircraft-specific procedures on an as-needed basis. This authoring system concept is described in Section 3.

The F-16 repair and modification facility would benefit from an electronic aiding system. F-16-related activities meet the criteria of being long, complicated tasks on a variety of equipment, requiring table look-up, information integration, high perceptual demand, and high criticality of correct performance. The activities of checkout and fault localization during modification could be done much faster with an IMAS than with paper manuals. Using the manuals as references for solving problems not proceduralized in the TO would also be feasible on an IMAS.

However, it is not clear at this time how, or how much, an IMAS capability would be used for modifications in the production area. The procedures for aircraft modification are specific to a TCTO, have a limited period of use, and change during the period in which the modification is being accomplished. An IMAS is not likely to be cost-effective for this activity.

2.4.2 Precision Measurement Equipment Laboratory

PMEL supports all other maintenance areas at Hill AFB by inspecting, calibrating, repairing, and overhauling all measurement equipment required for aircraft maintenance. The Electro Mech/Optical Dimensional Section is responsible for approximately 2000 devices, such as pressure transducers, optical alignment devices, weighing scales, and guided weapon test sets. Equipment is sent to PMEL either for periodic maintenance or when it is suspected to be faulty.

PMEL also supports organizational-level maintenance activities. When calibration-related problems occur in organizational maintenance, the equipment requiring calibration is either sent to the PMEL facility or PMEL technicians

travel to the site, where they either perform the calibration or determine if the problem is one of calibration at all.

2.4.2.1 PMEL Technician Activities--Significant PMEL time is spent writing technical documentation. When sufficient information is not available for organizational-level technicians to perform calibration and other related tasks, PMEL technicians will write TOs for these tasks, to be disseminated at the organizational level. In addition, PMEL experts must often write calibration and maintenance TOs if no documentation exists. They also write supplementary material to clarify existing (usually commercially produced) TOs.

Calibration of a particular measurement device requires knowledge at several levels of generality.

- The technician must have knowledge of the theory of measurement for a device (e.g., optics, electricity).

- The technician must be familiar with supporting equipment used for calibrating a device (e.g., simulators, frequency counters) and with its application to the particular device being calibrated.

- Since some of the equipment used at Hill AFB is more than 20 years old, the technician must be familiar with several models of supporting equipment and the various underlying principles or technology.

Much of the equipment maintained at PMEL is seen only at regular intervals, which may span up to six months. It is not cost-effective, therefore, for PMEL technicians to maintain one particular device. Although these technicians are certified in particular areas, they are required to maintain a large variety of equipment in many disciplines. Frequently, intensive exposure to a particular piece of equipment is not the rule, making memorization of procedures difficult and close use of TOs necessary.

2.4.2.2 PMEL Task Information--The TOs used by PMEL technicians are much less complete than those in other areas. Many PMEL TOs are written on the assumption that the basic procedures and related knowledge are already known by the reader. These TOs are basically expert-to-expert communications, since many steps are not spelled out in enough detail for a nonexpert to follow. For instance, many TOs provide calibration procedures formatted in a step-by-step list where the level of description and supporting information is appropriate only for the experienced technician who has performed the task before and needs little elaboration on the basic procedures.

For new or inexperienced PMEL technicians, additional detail is sometimes unavailable except from other PMEL technicians. For example, some TOs provide information on how to measure a particular tolerance value, but exclude procedures for adjusting the device when it is out of tolerance. In most cases, no rationale or explanation for the procedures is provided, making the procedures difficult to relate to what a new technician may already know about the principles of operation of a device.

When additional information is available, it lacks integration. Technicians must spend time searching for, and keeping track of, information scattered throughout one or more TOs. Too much information is provided, however, for the experienced technician, who must spend time looking for specific data.

This situation has resulted in the creation of subject matter experts at PMEL. These are technicians with many years of experience, who have learned the procedures not available in the TOs and are the only individuals qualified to perform some activities. For example, only two individuals can presently calibrate the MC-1 compass calibrator set, and only four can calibrate the Heads-Up Display (HUD) alignment equipment. PMEL is forced to rely on a small number of experts, and their unavailability can cause delays in maintenance activities, both at PMEL and the aircraft maintenance facility.

2.4.2.3 PMEL IMAS Candidacy--Because many tasks are performed relatively infrequently and on an extremely wide range of equipment, PMEL satisfies many of the criteria for application of job aiding. Calibration of optical alignment, boresighting, and electronic frequencies are long, complex procedures. Aiding is needed for these tasks. Calibration of some devices, such as pressure transducers and weighing scales, is fairly standard and independent of specific devices. They present few problems.

The use of aiding includes support for long-term memory (e.g., procedures), short-term memory (e.g., calculation), and perception (e.g., equipment subcomponent identification). A method of writing TOs and incorporating aiding in task performance is highly recommended. It would be extremely beneficial to allow less experienced personnel to perform without expert intervention and to preserve the PMEL expertise that is now handed off verbally.

In sum, PMEL would benefit from an electronic aiding system. PMEL activities meet the criteria of being long, complicated tasks on a variety of equipment, requiring table look-up, information integration, high perceptual demand, and high criticality of correct performance.

2.4.3 Landing Gear Division

The Landing Gear Division is an industrial, assembly-line plant for the inspection, retooling, and assembly of landing gears. When landing gear arrives, it is first completely disassembled. The component parts are inspected and sent to the different areas of the shop. Automation has been introduced in several operations, especially those that present potential risk, such as removing paint, cleaning, and impregnating parts with dye for subsequent visual inspection for structural defects. Other inspections are manual and visual, such as checking diameters of pieces and holes. Components that do not meet tolerances are discarded or sent to a machine shop for reworking. Finally, landing gears are reassembled using rebuilt pieces.

Although this area was considered a prime candidate for an IMAS before closer inspection, we have concluded that there is little need for an IMAS in this facility. Most jobs are highly structured, standardized, and repetitive. Most technicians do the same job for periods of several months and perform the same tasks many times a day. Technicians can soon remember the procedures by rote and rarely need to consult the TOs. Therefore, it is difficult to see any clear benefits--like reduced numbers of personnel, skill demands, or performance time--that can be related to significant increases in productivity or quality of maintenance.

However, there is a need in the Landing Gear Division for a planning and tracking system. The primary need is to compile, report, and update time and material standards for the repair jobs. This kind of system is easily within the state of the art in management information systems. The principal activities to be supported are collating, sorting, and reducing a large volume of data on job times and material usage. The tracking system would require an interface with the work flow to provide job performance data. The planning system would require an interface with ATOS for applicable planning data.

2.4.4 Sheet Metal Shop

Metal working is not a candidate for an IMAS application. Most of the work involves modifying parts. A particular modification is done repetitively until all aircraft in the inventory have been modified. The technicians soon overlearn the procedures and associated data and can perform the tasks without referring to procedural guidelines. The perceptual/cognitive demands are initially impressive, but the frequency of performance eliminates memory problems. The technicians seem to know, for example, the location and size of every rivet in the wing assembly on which they are working. Some manual skills, such as operating an electric drill, are critical, but they cannot be aided by an IMAS.

There was a high training need in this facility at the time of this study. This need was short-term and atypical, however. It arose from an expansion of workload created by a wing modification for one type of aircraft.

2.4.5 Automatic Test Equipment (ATE) Facility

Technicians in the ATE facility could benefit from some kind of aiding, especially in fault localization after the ATE has narrowed the source to a limited number of components. However, this need is not adequately defined to assess the applicability of an IMAS.

Two other approaches seem to be more relevant. Skill and experience in electronics are important and should be given emphasis through training and recruiting practices. Unfortunately, these qualifications are also in demand in several other jobs that provide greater financial rewards. At the ATE facility, reducing personnel turnover may be more useful than performance aiding. Further, integrating aiding directly into the ATE is a better way to provide support; no good way of integrating an IMAS with existing ATE was apparent.

2.5 RECOMMENDATIONS FROM DEPOT MAINTENANCE REVIEW: AIDING CANDIDATES

Several application candidates for aiding have been identified and screened for suitability as prototypes for demonstration and evaluation. Construction of these prototypes is recommended as the first phase in a long-range program.

Recommended applications are

- Integration of TOs for checkout of the F-16 flight control system
- Calibration of equipment used to maintain the MC-1 magnetic compass
- Calibration of equipment for boresighting the 20-mm cannon
- Calibration of equipment for optical alignment of the F-16 HUD

These candidates have been chosen on the basis of the selection criteria described in prior sections. There is a clear need for aiding in these areas among those that were reviewed at Hill AFB. There is potential benefit in terms of reduced task time, task difficulty, and probability of error. These factors, in turn, will reduce ability requirements, training time, and the number of people needed to maintain the aircraft systems. An IMAS-type system also is compatible with the activities and work situation at depot.

This study effort was restricted in scope and did not include a formal, quantitative cost/benefit analysis. It was intended as a front-end analysis of feasibility and potential benefit and as a projection of how to implement interactive aiding in depot maintenance. These recommendations reflect our best, experienced, quantitative judgment and are based on the information we were able to collect in the time allotted, limited on-site discussions with maintenance and planning personnel, and our evaluation of that information.

More detailed analysis of this depot-level problem depends on defining a more detailed IMAS concept for these applications and then devising a work plan for implementation. Estimates of cost factors are dependent on this level of detail. Subsequent sections of this report will contain a system concept for interactive maintenance aiding, a definition of two key prototypes to be developed, and a long-range development plan for implementing interactive maintenance aiding at the Ogden ALC.

The two recommended prototypes are

- An IMAS for the integration of maintenance instructions for checkout and fault isolation in the F-16 flight control system

- An IMAS for calibration of the MC-1 compass

The flight control system is a complex but representative area in F-16 maintenance. We have reviewed the TOs and believe that adequate information exists to proceed with design and implementation. The resulting system will be adaptable to other F-16 areas. The MC-1 calibration task is one of three applications we have identified within PMEL. The MC-1 compass prototype is recommended first because it is smaller in size, adequately structured, and representative of the needs and problems in PMEL.

SECTION 3

PRELIMINARY INTERACTIVE MAINTENANCE-AIDING SYSTEM CONCEPT

In this section, a preliminary IMAS concept for application at Hill AFB is described and basic functional specifications are presented. A development roadmap for individual application testbeds and an implementation roadmap for expansion to other tasks on the base are discussed.

3.1 IMAS CONCEPT

Performance aiding using electronic documentation can be very different from paper-oriented aiding. The translation of paper aids into on-line electronic aiding requires more than reprocessing words if advantage is to be taken of the great potential of the medium.

Therefore, electronic documentation is not just electronic page-turning. It is a procedure for presenting information, not just the information per se. There are large benefits to be gained by recording paper-oriented information in electronic form for the purpose of updating, publishing, and distribution. However, there are forms of information recorded by the computer that are not easily translatable into a paper equivalent. To take advantage of the full range of interface techniques that can be obtained with electronic documentation, the paper metaphor must be augmented.

3.1.1 System Overview

The objective of the IMAS concept is to provide the technician with information aids that will assist in long-term memory storage, short-term memory capacity, perceptual limitations, and/or reasoning capability. The aiding techniques should take advantage of the large potential of the electronic medium. The two basic components of the proposed IMAS are designed to achieve this objective.

- IMAS will provide a library of work packages to the technician, created from multiple information sources, including ATOS files.

- An authoring system will be provided to allow interactive creation, modification, and updating of interactive maintenance-aiding material, and to facilitate the integration of information from multiple sources into work packages.

Work packages are sets of software consisting of highly cross-indexed and easily accessible procedures and data. They are the final aiding product to be used by technicians on delivery hardware.

The work packages will be created by the use of an authoring system and supplementary compilation functions, as shown in Figure 9. A good authoring system guides an author through the writing process by a series of menus that permits the author to choose the information to present, the format, and the method of presentation.

Procedural and graphical information from the current TOs is stored in digitized form on ATOS. ATOS files and other supplemental information (e.g., selected aircraft maintenance histories) will be entered into the IMAS authoring system, where it will be integrated with advanced aiding techniques by a combination of:

- Automated creation of default authoring choices by the system
- Handcrafting of aiding techniques interactively selected by the author
- Automated integration functions (e.g., automatic access of cross-referenced information sources and documents)

In the recommended F-16 application, the work packages will be constructed in a two-step process that will strip off information not related to the specific aircraft being modified. The authoring system will allow the creation of appropriate aiding for all segments of possible F-16 maintenance procedures.

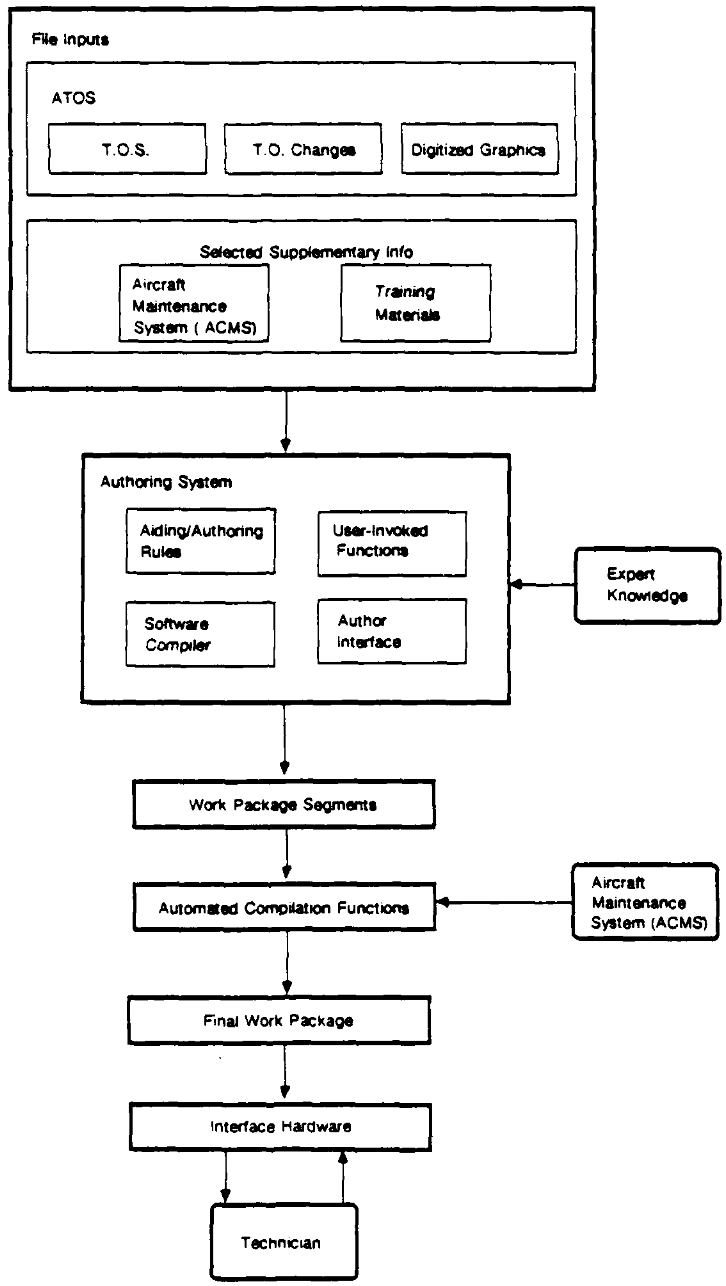


Figure 9. Architecture of the Major Components of IMAS

These procedural segments are then available for compilation into final work packages containing only those procedures applicable to a particular aircraft.

In this way, entry of a particular aircraft tail number into the system will call up its modification history from the existing ACMS. Using this history, the system can selectively compile the relevant preauthored work package segments containing those maintenance procedures, schematics, illustrated part breakdowns, etc., that are applicable to the particular aircraft.

The resulting work package data and software will then be available for subsequent use by the technician in on-the-job delivery hardware. Running this software program on delivery hardware yields the final system output: graphics and text overlays combined to form an integrated information access and display that is optimized for the maintenance technician's tasks.

This same system can be used for any application area where there is more than one procedure for a particular type of equipment because of multiple configurations. Though a significant amount of cross-referencing still will be required, the recommended PMEL application will require less stripping than the F-16 application, and the work package segments will be closer to final work package form. In addition, the capability to create and amplify calibration procedures will be supported.

3.1.2 The IMAS Authoring System

The heart of the IMAS concept is the semiautomated design of the maintenance-aiding interface and the selection of interactive aiding techniques and job information to be included in electronic work packages. The IMAS authoring system is conceived as a tool that helps transform paper-oriented electronic documentation, primarily from ATOS, into a portable (i.e., relatively machine-independent) software program for delivering advanced, computer-based aiding. The characteristics of the authoring system are listed in Table 3.

TABLE 3. CHARACTERISTICS OF THE PROPOSED IMAS AUTHORING SYSTEM

- Interactive
- Menu-driven
- Input includes ATOS files, ACMS maintenance histories, and user expertise
- Automated authoring functions wherever possible
- Facilitates cross-referencing and integration of relevant information
- Incorporates and enforces advanced maintenance interface techniques
- Generates aiding options for user when possible (e.g., highlighting)
- Automatic or semiautomatic stripping function (dependent on inputs, e.g., ATOS)
- Output is portable software (relatively machine-independent)

The author is expected to be a skilled depot-level engineer with personal knowledge of maintenance jobs, TOs, and other information sources. The author should be in a position to improve aiding packages based on reported problems or suggestions from reputable depot technicians. The author will be expected to acquire some knowledge of the aiding techniques available in the authoring system, preferably through a basic training and decision-aiding facility embedded in the system.

The system will be designed for ease of use. It will be menu-driven rather than reliant on a specialized programming language and its attendant requirements for expertise in direct programming.

The workload of the IMAS author will be reduced wherever possible by the use of automatic routines for integrating related documents and generating standardized aiding techniques. The system will incorporate as many built-in functions for simplifying and standardizing the authoring task as possible. Given suitable input, the system could generate the bulk of the aiding and integration functions automatically for validation by the author/user. Given embedded cues (e.g., control characters) in the ATOS files and other information sources, the IMAS authoring system could generate a first-cut version of the final work packages, to be "fine-tuned" by the author. Significant time would be saved compared to handcrafting the work package from start to finish.

Aiding rules, encoded in the authoring system, will enable the enforcement of uniform, standardized production of the final aiding product by creating a first cut for subsequent author validation. These rules would be triggered whenever there is sufficient information to enable their use. For example, the proposed IMAS authoring system might take ATOS-based text and graphics as input and produce a work package segment that allows TOs cross-referenced in a particular screen of text to be accessed by means of a window of menu items, each corresponding to relevant TO information. The author would then be given the option of including this first-cut menu in the final work package.

A file of interface techniques, such as those in Table 1, will have corresponding authoring functions built into the IMAS authoring system. The effectiveness of various aiding techniques at this level has not yet been validated. Therefore, the file of techniques will be compiled on the basis of engineering judgment. It will be modified as its benefit is proven in collateral development studies.

The IMAS authoring system will contain a number of automated functions that are relatively independent of author control. Information stripping is a critical aspect of F-16 maintenance aiding since an extremely large portion of the technician's time is spent searching for information and procedures appropriate

to a particular aircraft. Both TO changes and conditional job guide procedures create the opportunity for serious and costly errors.

3.1.3 ATOS Compatibility

ATOS is designed to contain a large amount of indexing information that will be needed for input into the IMAS authoring system, particularly for indexing related documents (Reference 10). The ATOS file structure is probably adequate for the purpose of accessing TO files that are cross-referenced within documents. However, it will be desirable for the authoring system to automate aiding technique options within TO procedures. ATOS provides the needed capability of accessing intra-TO information by superficial document structure (e.g., page number, paragraph number, table or figure number, etc.), but it does not describe procedures by content or form (e.g., branching, conditionals).

It may be desirable to recast the simple character strings in the ATOS files into another form, such as directed graphs, a form similar to a decision tree. This form would allow the use of more highly automated authoring capabilities so that default treatments of procedural authoring could be automatically provided. The authoring system could then detect a conditional branch based on, say, the equipment version, and do a better job in stripping off irrelevant procedures. An authoring system can produce a directed graph representation of procedures as an adjunct to its final aiding product, but a tradeoff analysis remains to be performed to determine the most effective time and way for this information to be entered.

To author TOs and corresponding work packages from scratch, the IMAS authoring system can be used in conjunction with the planned ATOS authoring system. The nature of this integration awaits further study.

The IMAS authoring system will be fully compatible with all ATOS files and capable of reading all special embedded control characters. The authoring

system will also need to extract cues from the ATOS conventions in order to automatically generate aiding options for the author. Further study needs to be performed on this and other aspects of the IMAS-ATOS communications interface.

3.2 MINIMUM IMAS SPECIFICATIONS

The scope of this study did not allow the development of detailed specifications for an IMAS system. However, some minimum requirements were developed based on overlap in information delivery needs between several potential application areas. A detailed functional specification awaits further study of the ways that available information delivery methods can enhance the problem-solving methods employed by technicians in particular classes of tasks.

3.2.1 Indexing

A rich indexing system will be provided that allows easy access to relevant information. The technician will be able to access all relevant information by specifying the system or device, using highlighted or menu selections from the current display, or employing user-transparent access and display whenever possible. For information that cannot be supplied directly to the interface (e.g., training packages, video tapes, maintenance histories), the system will specify the method of obtaining that information in a convenient and easily understandable manner.

Cross-indexing will be achieved in a user-transparent manner. When cross-indexing occurs between relevant files, the authoring system will enable the prestructuring of work packages so that the burden will fall on the delivery system rather than the technician to access and display that information. The technician will use menu selection by mouse, touch screen, or cursor control to access cross-referenced information. An extended example of this concept, accomplished by highlighted key words, is presented in Figures 2 through 6.

3.2.2 Information Filtering

When procedures vary according to equipment version, only those procedures that are applicable to the present equipment are displayed. This is particularly applicable to tasks like F-16 modifications in which each aircraft has had a different set of modifications performed on it, thereby making a standard set of procedures impossible to construct. Present TOs have a confusing, time-consuming, and error-prone system of determining which procedures apply to which aircraft. An important feature of an IMAS is the ability to display only those procedures applicable for a particular technician working on a particular aircraft with particular modifications.

3.2.3 Interface Display Techniques

Information will be displayed according to principles consistent with research in computer-user dialogue, attentional focus, information integration, and other human factors that may impact speed and accuracy of performance. A provisional list of techniques and their uses is presented below, in rough order of applicability. Tradeoff analysis is necessary to determine the full requirements for each operational organization (for example, PMEL or F-16).

- Highlighting: Illuminating areas of the screen to attract attention to a key event

- Hypertext: Highlighting key words and elicitation of supporting or explanatory information by touch, mouse, or cursor mechanisms; a method for presenting definitions, higher levels of explanatory detail, cross-referencing, or deeper menu structure; also used to provide low level of detail for experienced technicians while still providing another "layer" of explanation for less experienced personnel

- Split screen techniques: The simultaneous presentation of text, graphics, segments from multiple information sources, "folding" of schematics, etc.

- Windowing: Similar to split screen techniques; used for temporary displays like menus and warnings

- Overlay techniques: Methods for decluttering detailed graphics and filtering out unneeded visual information; similar to cellophane overlays in paper media

- Scrolling, panning, and zooming in an area or block: Methods to move digitized graphics up, down, right, and left, and to change the pictorial scale to a higher or lower resolution

3.2.4 Special Information Content

Specialized integration aids will provide the means to use information from traditionally separate sources.

- Bookmarking: The capability of "marking" a place as in a paper TO so that a technician can interrupt a task and continue later without backtracking

- No-fault values: The option of supplying nominal values directly on a graphic rather than having technicians manually annotate drawings

- Functional block diagrams with animated input/output flow: A method of showing information process flow between functionally distinct components of the system under maintenance

- Functional block diagrams with varying detail of functionality on request: Display of a subsystem or component at the next level of detail

- Connection highlighting: A method of graphical selection of the input or output point for signal tracing

- User calculation/automatic calculation: A system capability for performing complex or lengthy mathematical calculations for the user

- Annotation: The capability to make notes on graphics or "in margins"

SECTION 4

IMAS DEVELOPMENT PLAN

4.1 ROADMAP FOR IMAS IMPLEMENTATION AT OGDEN ALC

A three-year roadmap for implementing an interactive maintenance-aiding system for depot maintenance and support activities at Ogden ALC is presented in Figure 10. The basic concept is to develop aiding and authoring system prototypes in selected application areas in order to test key concepts on a small scale. These prototypes will then be extended to more comprehensive implementation after the concepts have been validated.

The key to successful IMAS implementation is the development of specific prototypes, represented in this roadmap as the target of first-phase activities. IMAS prototype development calls for two parallel projects: an F-16 application for checkout of the flight control system and a PMEL application for calibration of optical equipment. These projects will be described in more detail in subsequent sections.

The purpose of prototype development is to provide an application testbed at the depot level and a near-term interactive maintenance-aiding product that then can be used in a long-range plan of system development. The prototype can be used to:

- Test interface techniques for interactive maintenance aiding
- Gain experience with the pragmatic factors of implementation in the operational environment
- Demonstrate the utility of the system
- Generate realistic quantitative estimates of cost/benefit components

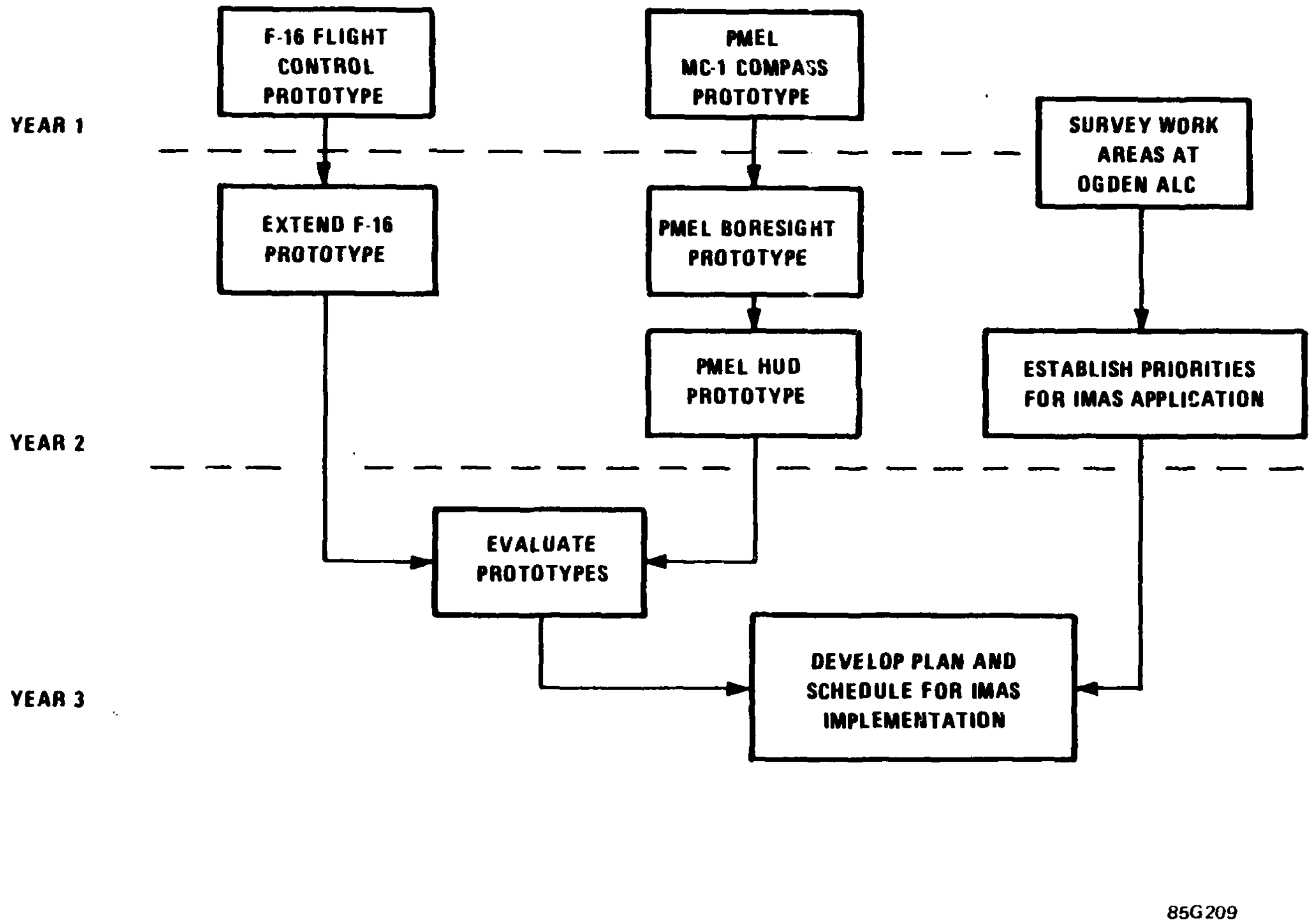


Figure 10. Roadmap for Implementing an Interactive Maintenance-Aiding System at Ogden ALC

In developing the authoring system, the testbed will be particularly useful as a vehicle for interactive use of available information from ATOS and other sources, including experts.

In addition to the central activity of prototype development, the IMAS roadmap includes a timely, comprehensive survey of other maintenance and support activities at Hill AFB, to be undertaken during the first two phases. This survey should be conducted as the recommended prototypes are being developed. The results of the survey should be used to assess each additional area for potential benefit from aiding and to assign a priority to each candidate application on this basis.

It is recommended that some collateral technology issues be addressed as part of the IMAS roadmap. Study will be needed on:

- The specific task conditions under which particular aiding solutions should be invoked (automatically by the authoring system where possible)

- The design of necessary help functions and decision aids for the author

- The desirability of embedded training functions that could be incorporated as part of the interface's explanation capabilities

Other DoD programs will be addressing similar, related issues and applications. Relevant Air Force programs include ATOS, the Integrated Maintenance Information System (IMIS), and the Flight Control Maintenance Diagnostics System (FCMDS). The IMAS implementation roadmap will allow the identification of potential problems common to all of these programs before large-scale implementation is attempted.

There undoubtedly will be continuing progress over the course of IMAS implementation in areas such as artificial intelligence, intelligent systems,

and virtual interfaces to computer systems. It is implicit in our roadmap that these developments will be monitored and incorporated as feasible. However, it is imprudent to predict and rely on specific functional breakthroughs and we will not attempt to do so.

4.2 PHASES OF PROTOTYPE DEVELOPMENT AND IMPLEMENTATION

Development of the two prototype applications will follow the same sequence of generic steps. IMAS development and implementation consists of four phases. It is assumed that a maintenance application area with payoff for information aiding and a representative set of tasks have been selected to demonstrate the suggested capabilities of the system.

- Phase 1 consists of developing a detailed design and implementation plan for the prototype. Detailed task analyses of the jobs to be aided and information flow diagrams of the authoring and aiding functions will be developed. The objectives of this phase are to provide the following information:

  --Performance specifications for the system created by analyses of the maintenance activity

  --A system design concept at the level of system functions or "black box" components

  --A detailed engineering specification for fabrication of the aiding system

  The information generated during this phase should be adequate to support the subsequent writing of a statement of work for construction or procurement of the system. The information should also be adequate for specifying the job aiding required, providing a basis for

cost/benefit analysis, and identifying collateral studies for capturing data on specific design issues and for rapidly prototyping system features.

- Phase 2 consists of building and installing the prototypes in the selected job areas. Technicians will be familiar with the new system, and the prototype will be evaluated using performance data and technicians' subjective responses. The IMAS concept will be revised as necessary.

- Phase 3 consists of testing and evaluation. A test plan for evaluating the effectiveness of the prototypes will be developed, and an adequate number of users will complete standardized exercises to provide data for evaluation. Reports of system deficiencies and experience accumulated with the system will be compiled and used for redesign.

- In Phase 4, the prototypes will be expanded to other maintenance activities within the operational organization. The extension to other activities should be preceded by a survey of these activities and an analysis of the potential benefit from aiding. Implementation can then be scheduled based on this analysis.

The plan calls for concurrent, parallel development of the prototype applications and the authoring system. As aiding techniques prove beneficial, they will be incorporated as authoring system capabilities. Though authoring functions will be incorporated only as needed within a particular application, a high level of transfer to subsequent applications is anticipated. Therefore, later applications are assumed to require little modification of the authoring capability.

IMAS software should be relatively machine-independent. Though standard, bench-mounted CRT and keyboard equipment will be used during development,

ultimately, configurations for specific work environments, such as a portable device for flight-line use, will be designed. Therefore, the aiding software must be "portable" across different types of display, input, and storage devices. Because the interface and information delivery prototypes will be developed without commitment to a particular delivery hardware, additional synergism can be gained by taking advantage of parallel development within other Air Force programs.

ATOS will have to be simulated for prototype development. Other related systems and sources of information under development may also need to be simulated. Candidate aiding techniques may have to be tested without waiting for the final system version or actual operational equipment.

4.3 PROPOSALS FOR DEVELOPMENT OF IMAS PROTOTYPES

Development of two prototypes is recommended. The first recommended prototype is an aiding system that provides a single integrated maintenance procedure for the technician doing checkout and fault isolation on the F-16. It is recommended that the prototype be limited to a portion of the flight control system. The second prototype provides aiding for optical calibration tasks at PMEL. The initial effort will be calibration of the MC-1 compass. The calibration prototype will then be extended to boresighting the 20-mm cannon and to the F-16 HUD.

4.3.1 F-16 Flight Control System Prototype

The proposed aiding system will display to the technician procedures for checkout and fault isolation for the F-16 flight control system. The prototype will be developed using a bench-mounted CRT and keyboard.

Desired procedures will be called by entering the aircraft tail number and the planned maintenance action. Only the procedures specific to that particular

aircraft will be presented; all other material will be removed. Branching within the procedure will occur on entry of the outcome of a maintenance action. All supporting and collateral information, graphics, illustrative material, and aiding techniques associated with the presented information will be incorporated as an integral part of the procedures.

Advanced aiding techniques will be incorporated to enhance the clarity and understandability of the procedures, reduce the cognitive/perceptual demands and difficulty of the tasks, and assist the technician in tracking and managing maintenance activities.

An explanation capability will be provided to enable the technician to request additional information on any task or step. As examples, the explanations may include diagrams of components at various levels of detail, rationale for a procedure or action, definitions of terminology, tracing of electrical current flow, and other material as it is discovered to be appropriate to the technician's tasks and ability. At least two levels of description of the procedures will be provided.

An authoring system will be provided to edit and compile ATOS and ACMS information and all desired aiding techniques into work packages to be delivered to the technician through appropriate delivery hardware. The authoring system will assist the author in the incorporation of aircraft-relevant material, cross-referenced ATOS files, and aiding techniques into work package segments. These segments will be available for compilation by supplementary program functions into final work packages.

The aiding interface used by the technician should be eventually incorporated into a lightweight, portable, hand-held device such as the Grid Compass computer being developed under AFHRL's IMIS program. The portable device should be explosion-proof for use on the flight line. The display must be legible in the range of ambient illumination encountered in depot and organization maintenance areas.

Technicians, supervisors, and planners will be consulted during the development of performance specifications, design, and implementation. User reaction and evaluation of projected ease and usefulness of system features will be obtained. Consistency between user evaluation and performance data obtained from collateral studies will be sought.

A roadmap of activities in developing, testing, and expanding the F-16 prototype is presented in Figure 11. Each of the phases--development of requirements and design, build, and test and evaluation--are allocated one year for completion.

4.3.2 PMEL Calibration Task Prototype

Three tasks have been chosen for initial prototyping:

- Calibration of the MC-1 and MC-1M compass
- Calibration of boresighting the 20-mm cannon
- Calibration of the HUD alignment equipment

These tasks were chosen because the procedures are very detailed, are performed infrequently, satisfy the criteria for aidability, and have available TOs. The compass calibration is the simplest of the three candidates. Designing aiding and authoring systems for this task will provide a baseline for expansion in the other two areas.

The MC-1 and MC-1M compass calibration equipment provides magnetic inputs to a magnetic compass system. The differences between the MC-1 and MC-1M are in the control console, power supply, adapter box, slaving control, and interconnector cables. The frequency, dc voltage, regulation, and synchro control of this equipment are calibrated by PMEL personnel. Procedures for both compass sets are contained in one set of TOs (TO 33K6-4-94-1 for calibration and TO 5N3-3-7-3 for overhaul).

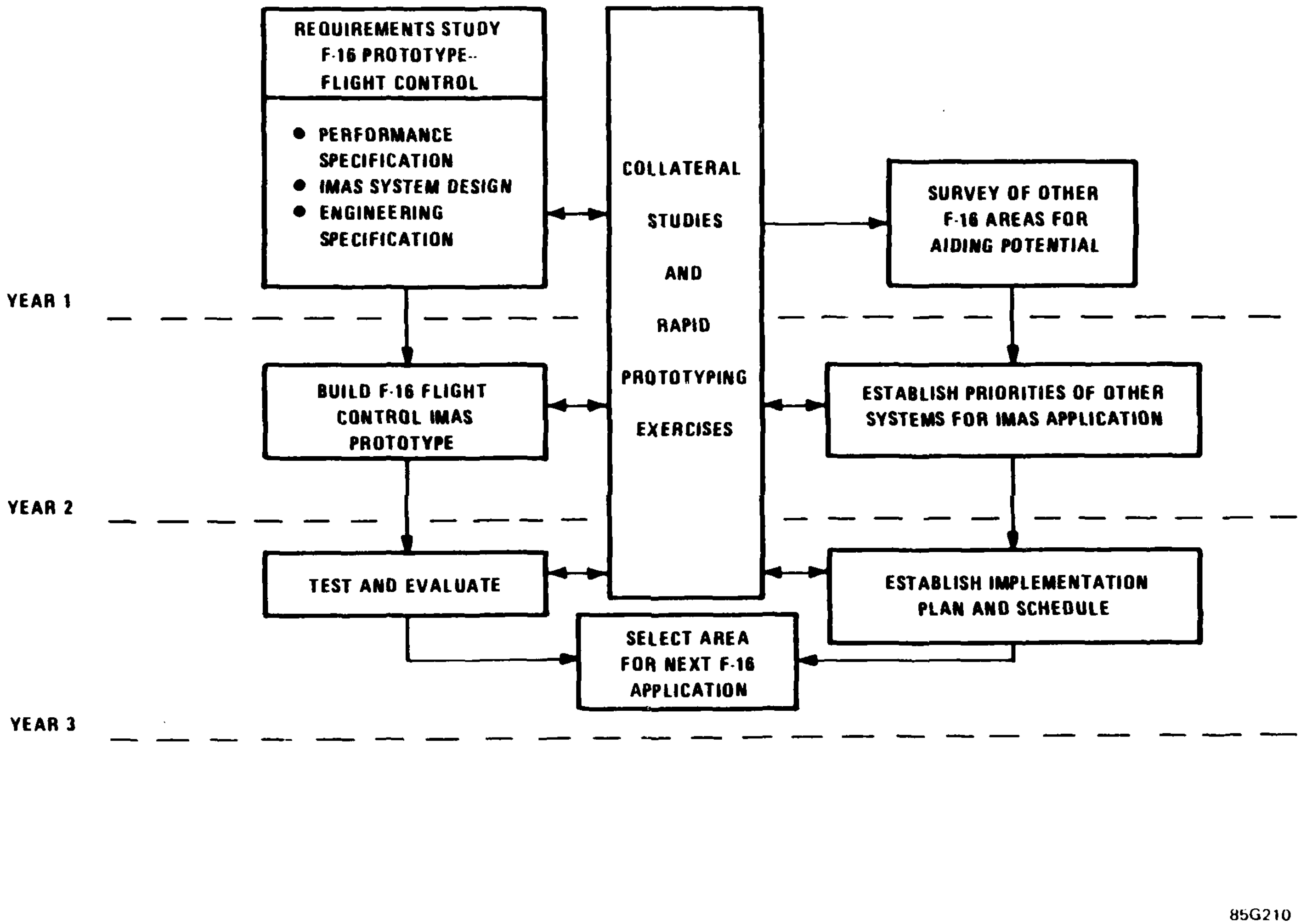


Figure 11. Roadmap for Developing a Prototype IMAS for F-16 Checkout

The HUD alignment set is used for calibrating the Heads-Up Display on the F-16. This equipment must be calibrated every six months, and the process takes roughly four to six weeks.

Table 4 is a list of the capabilities of the PMEL prototype sytem. Because most calibration procedures are done in the facility, benchtop CRT terminals would be the logical primary interface for the technician. Some calibration procedures must be performed outside of the facility, so portable terminals may also be needed.

TABLE 4. PMEL PROTOTYPE CAPABILITIES

Capability	Design Specification	Benefits
Easy access to information in TOs Access by menu selection Information tailored to skill level of technician	Indexing • Across related TOs • By key words (equipment numbers, components) • By major headings • With other information sources (e.g., training materials) Menu selection by touch input	Less time spent finding TOs Less time spent searching through TO for relevant information
Integration of information	Split screen/windowing capability	Simultaneous viewing of related information (e.g., illustrations and descriptions)
Preparation of TO materials Preparation of training materials	Authoring language • Provides ATOS format • Automatic indexing with related information • Graphics input • Digitized photographs	Less time spent preparing TOs Less reliance on subject matter experts at depot and organizational level

Keyboard use would be limited to setting up the work space for the particular task (e.g., loading required information). Once the information is on-line, the technician could input menu selections by touch to minimize the manual interaction of the technician with the terminal. Maintenance instructions will be presented in a menu format using windowing techniques, similar to the example presented earlier.

Occasionally, calibration tasks require the technician to perform lengthy and/or complex calculations on measurement data, for example, calculating the mean and standard deviation of several instrument readings. Current TO format provides a worksheet for these procedures. These worksheets have a space for user data inputs and provide instructions for required mathematical manipulations. The IMAS system should allow inputs from the keyboard for these procedures, perform the necessary calculations, and provide explanatory materials if desired.

The authoring system component of the proposed IMAS is a crucial part of this application. Though TOs already exist for the procedures selected for prototyping, the IMAS authoring capability could be readily tested by having technicians enter supplementary information on existing procedures that are not adequately detailed for nonexperts performing the calibration tasks. Once the procedures have been supplemented for aiding, the prototypes could be evaluated for effectiveness by testing whether technicians unfamiliar with the procedures could perform the calibration tasks more readily and without consultation with resident experts.

A schedule of activities for development of the PMEL prototype is presented in Figure 12.

4.4 COLLATERAL ISSUES

There are several areas in which further collateral study will be highly beneficial to the design and development of an IMAS:

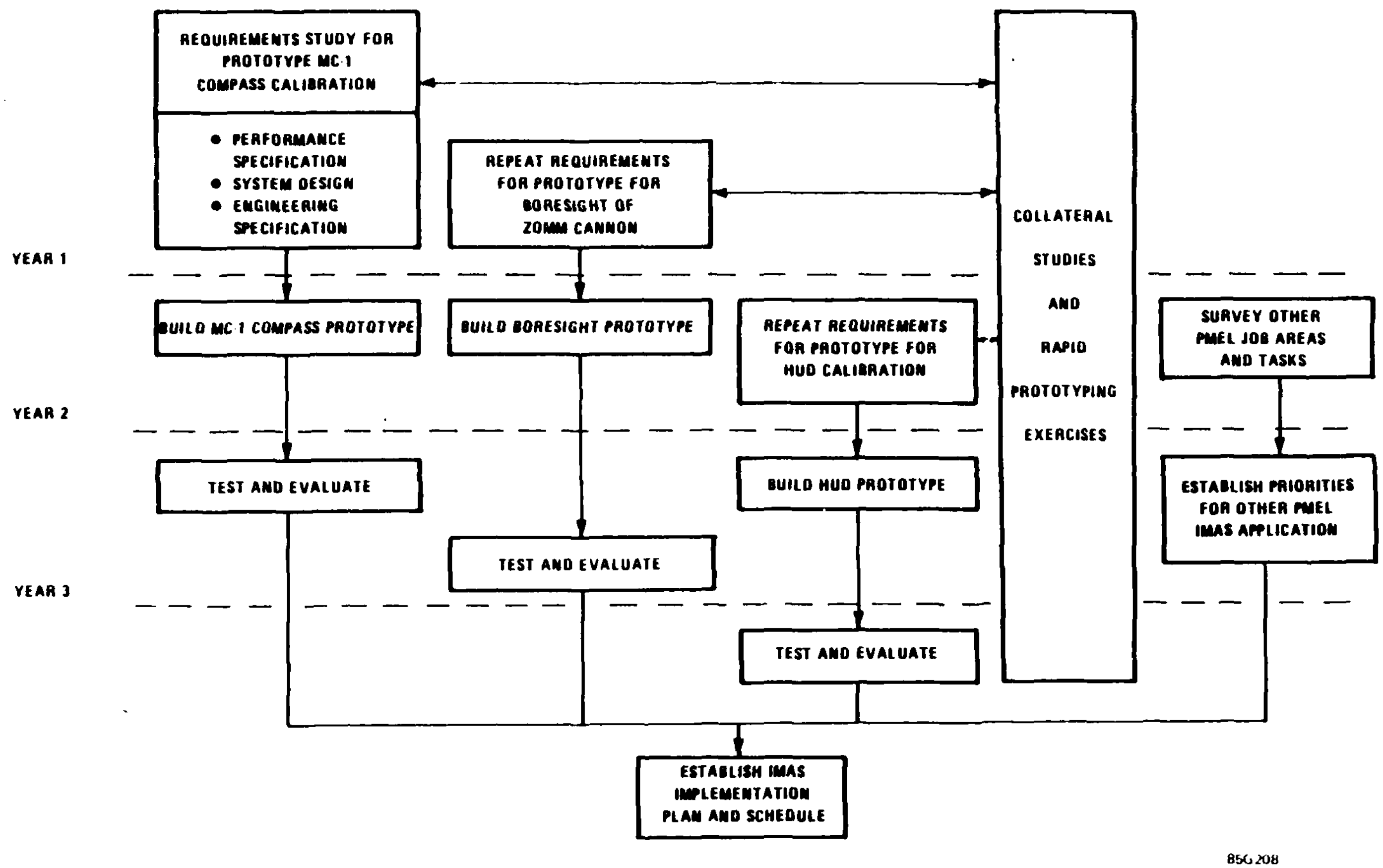


Figure 12. Roadmap for Developing an IMAS for PMEL

- Identification and design of necessary help functions and decision aids for the author
- Determination of aiding techniques required by specific maintenance task characteristics
- Desirability of incorporating embedded training functions into the interface's explanation capabilities

4.4.1 Help Functions and Decision Aids

The purpose of the authoring system component of IMAS is to generate effective work packages for use by the technician. An effective authoring system must provide a high level of support and decision aiding to the author. It can reduce the user's workload and enforce a reliable standard of quality in the work packages created. However, a system that permits an author to insert aiding indiscriminately can result in work packages that reduce productivity and encumber, not aid, the technician. To the extent that an authoring system can guide an author to the correct choice of aiding, the product will be consistently high in quality.

Therefore, an important objective is to construct a clever system that can generate desirable aiding whenever possible, providing the author with good default choices. In addition, the author should be provided with an embedded decision aid for selecting aiding techniques based on target task characteristics that may not be directly detectable by the system.

4.4.2 Aiding Based on Task Characteristics

Default aiding to the author can be provided by rules for the application of particular aiding techniques contingent on task characteristics (e.g., multiple procedural branches). The objective is to identify attributes of maintenance tasks that suggest particular forms of aiding. These attributes should be systematized into a decision aid for the author, providing automatically

generated aiding options where possible or providing a help facility for determining aiding techniques on the basis of task characteristics.

4.4.3 Embedded Training

Another issue for study is the determination of the desired amount of embedded training to be incorporated into the IMAS interface. Menu-driven explanation can be used for on-the-job training. A set of explanations can be designed to lead a technician through a complex task or cognitive procedure. Diagnostic feedback could also be provided for correcting errors. The extent to which explanation on the job can replace prior classroom training is an important issue in the utility of interactive aiding systems. The reduction of ability requirements and training time may produce significant cost savings while maintaining or enhancing productivity.

4.5 WHAT TO DO NEXT

The next action to be taken is to initiate the requirements analysis for prototype development. Perhaps the quickest approach is to extend the present work with a contract to develop the requirements. The level of effort should be one person-year executed in a six-month period. The objective of the contract should be to provide the information necessary for a statement of work to be used in a procurement to build the prototype aiding demonstration. The study should cover both the F-16 flight control and PMEL applications.

The principal activity of the contract would be a detailed analysis of the tasks to be aided and an information flow diagram of the authoring and aiding functions. The objectives of the study would be to provide the following information:

- Performance specifications for the system derived from an analysis of the maintenance activity

- A system design concept at the level of system functions or "black box" components
- A detailed engineering specification for fabrication of the aiding system

The level of detail in this information should be adequate to support the subsequent writing of a statement of work for construction or procurement of a system. It should be adequate for specifying the job aiding required, providing a basis for cost/benefit analysis, estimating the levels of effort required, and identifying collateral studies to capture data on specific design issues and to rapidly prototype system features.

If the requirements analysis is done on contract, the final result of the study should be a sequence of tasks for building the prototypes. These tasks would then be converted to the statement of work for a request for procurement.

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